Validation of MODIS aerosol observations over the Netherlands with GLOBE student measurements

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The GLOBE Program

KNMI

= **G**lobal **L**earning and **O**bservations to **B**enefit the **E**nvironment – since 1995

GLOBE is specifically aimed at high-school and elementary level

Pilot project with 5 Dutch high-schools starting in 2002

Why a student-based aerosol validation project?

1. Outreach

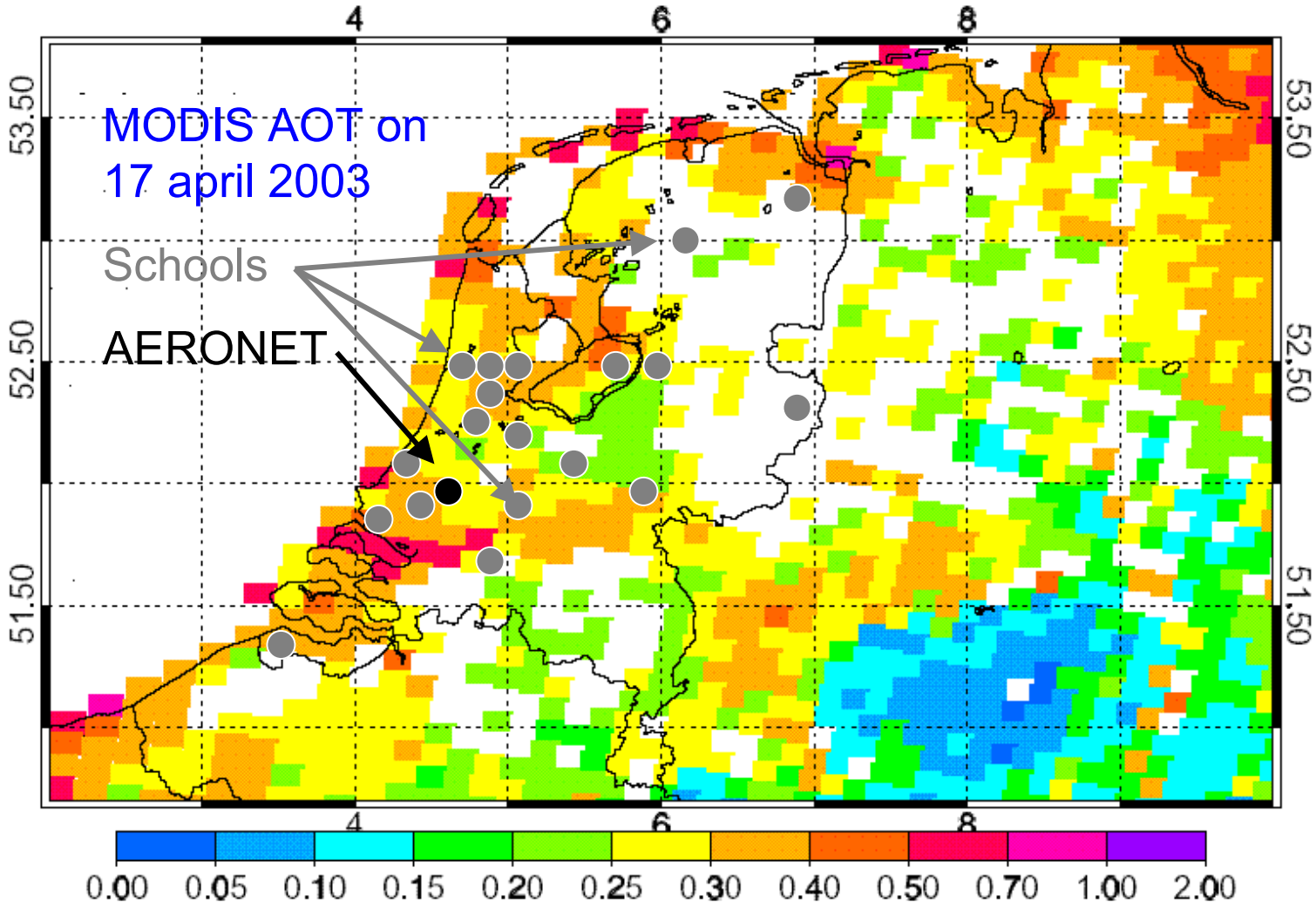
- get satellite research (OMI) and
- atmospheric research to schools
- generate publicity for OMI

2. Science validation of OMI aerosols (and first MODIS as a demonstration)

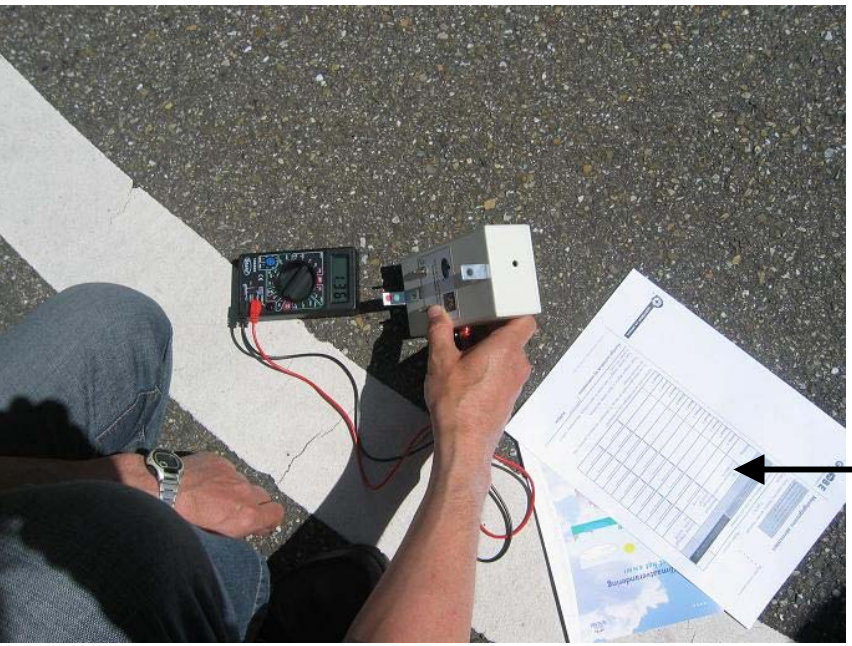
The GLOBE Program

KNMI

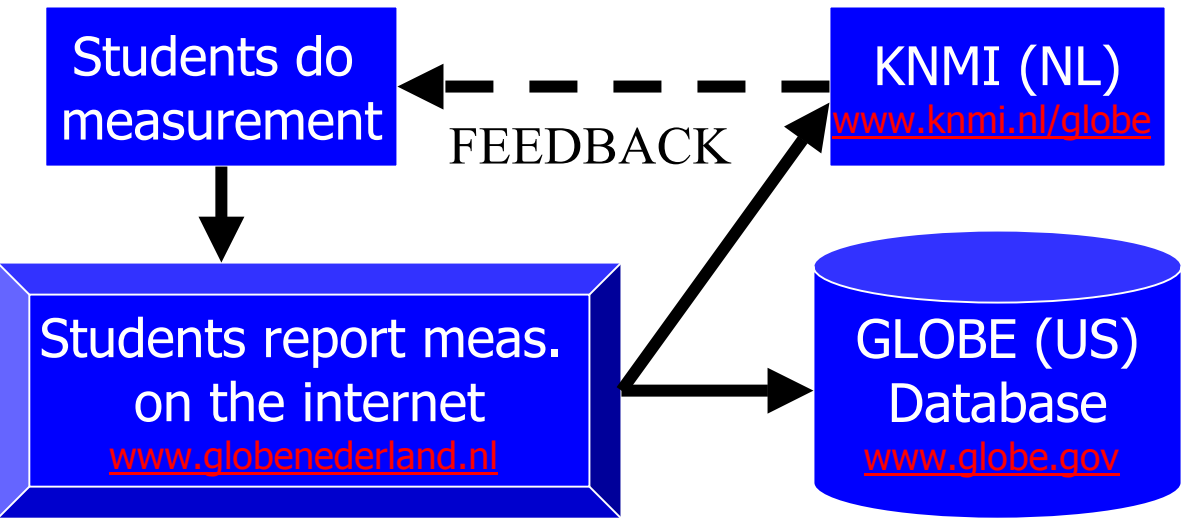
School measurements provide potential for dense network that cannot be reached with professional instruments! (D. Brooks – Drexel University)



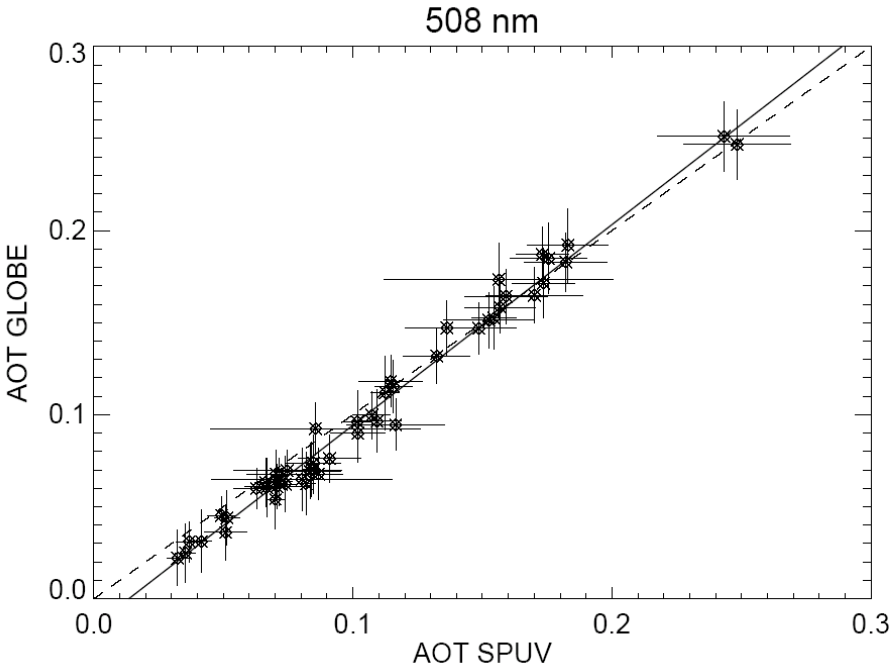
•••• How do students measure AOT?

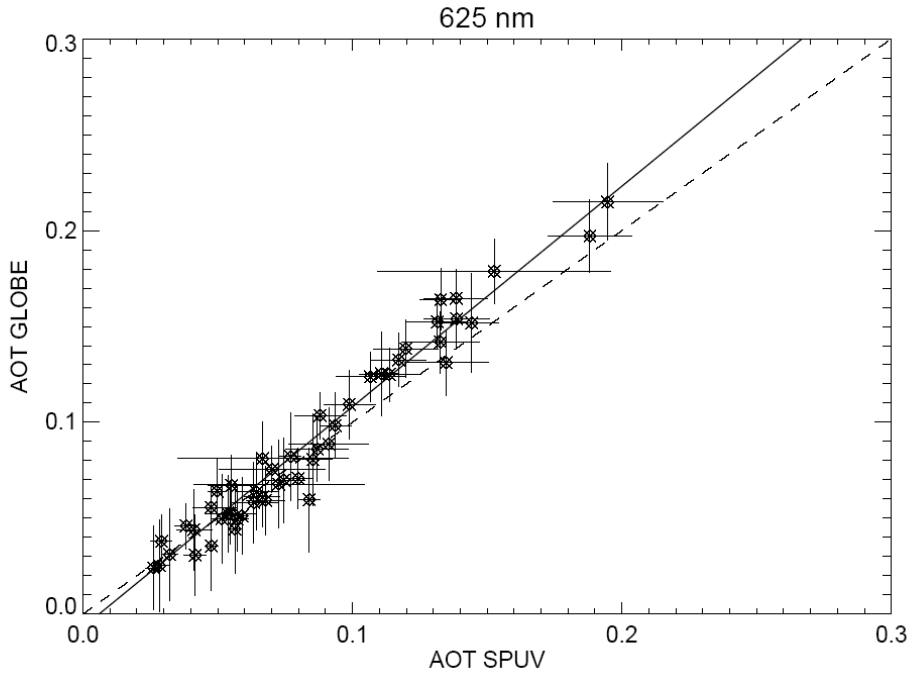


- Use a simple hand-held Sun photometer developed by D. Brooks
- Point to the Sun in a cloud-free sky
- Two LEDs detect light at 508 nm and 625 nm
- Record light intensity, local time, surface pressure
- Apply Lambert-Beer's law



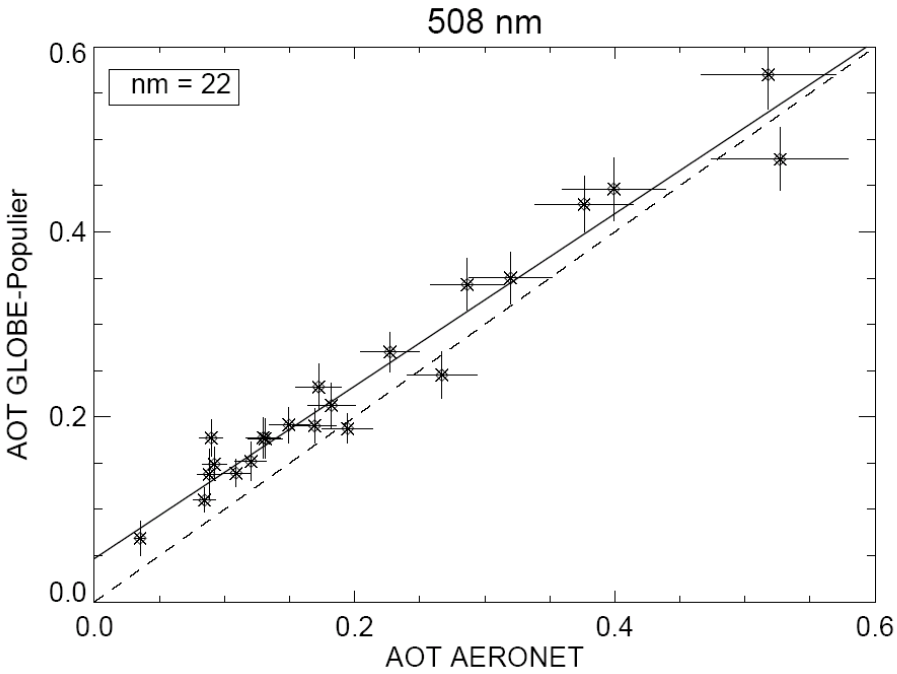
•••• How good is AOT measured by a simple Sun photometer?

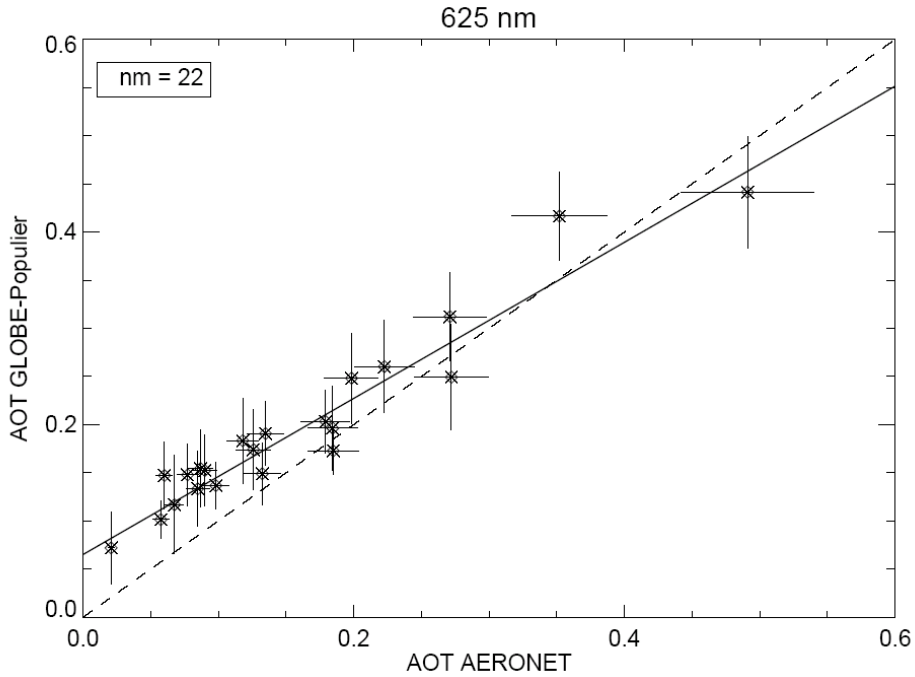




Location	n	R^2	Bias	RMS	Regression
KNMI 508 nm	49	0.992	-0.005	0.009	y=-0.02+1.10x($\pm$0.06)
KNMI 625 nm	49	0.980	+0.004	0.012	y=-0.01+1.15x($\pm$0.08)

•••• How good is AOT measured by students with a Sun photometer?





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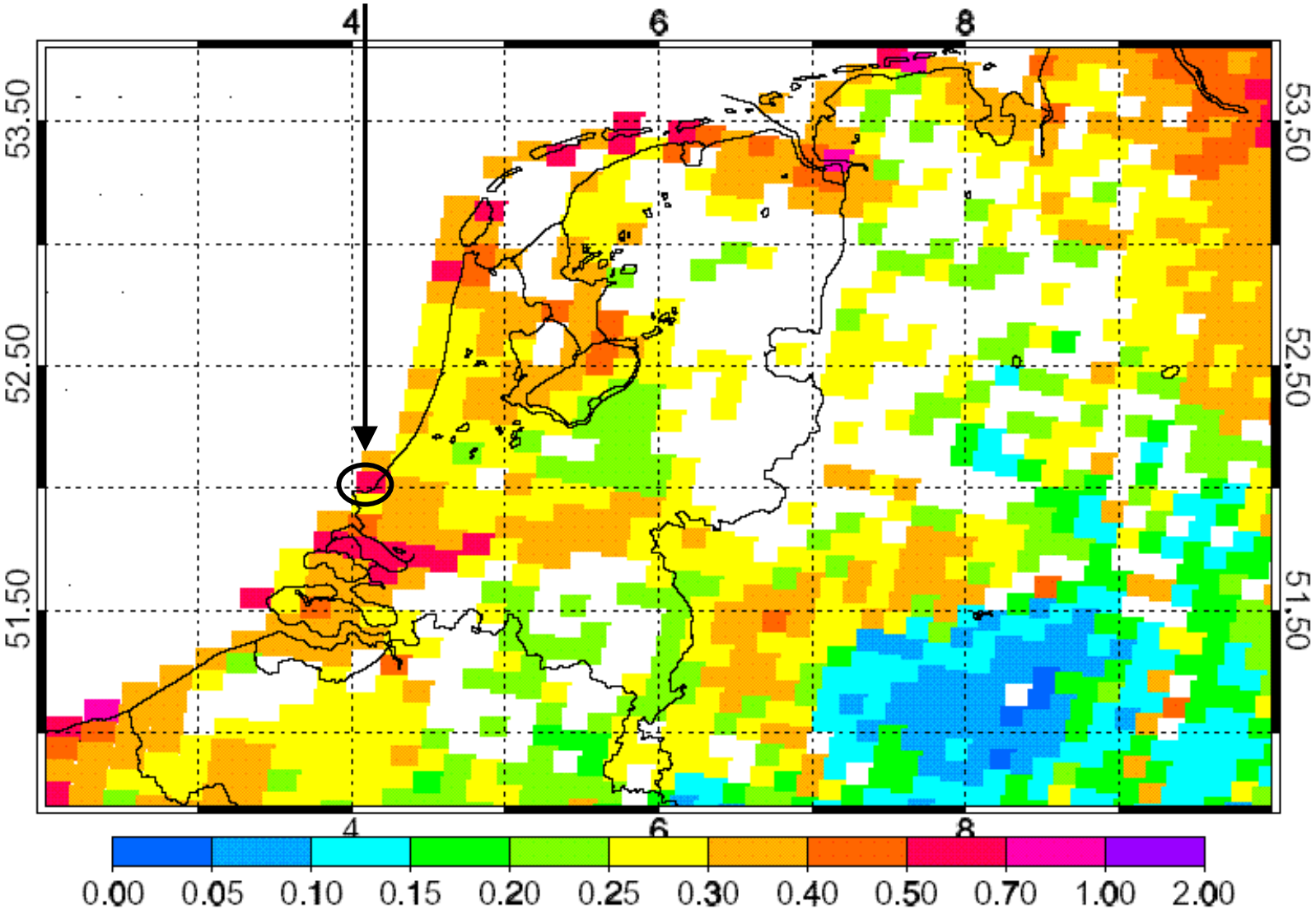
KNMI 508 nm	49	0.992	-0.005	0.009	y=-0.02+1.10x($\pm$0.06)
KNMI 625 nm	49	0.980	+0.004	0.012	y=-0.01+1.15x($\pm$0.08)
De Populier 508 nm	22	0.956	+0.035	0.029	y=0.05+0.93x($\pm$0.06)
De Populier 625 nm	22	0.927	+0.039	0.033	y=0.07+0.81x($\pm$0.10)

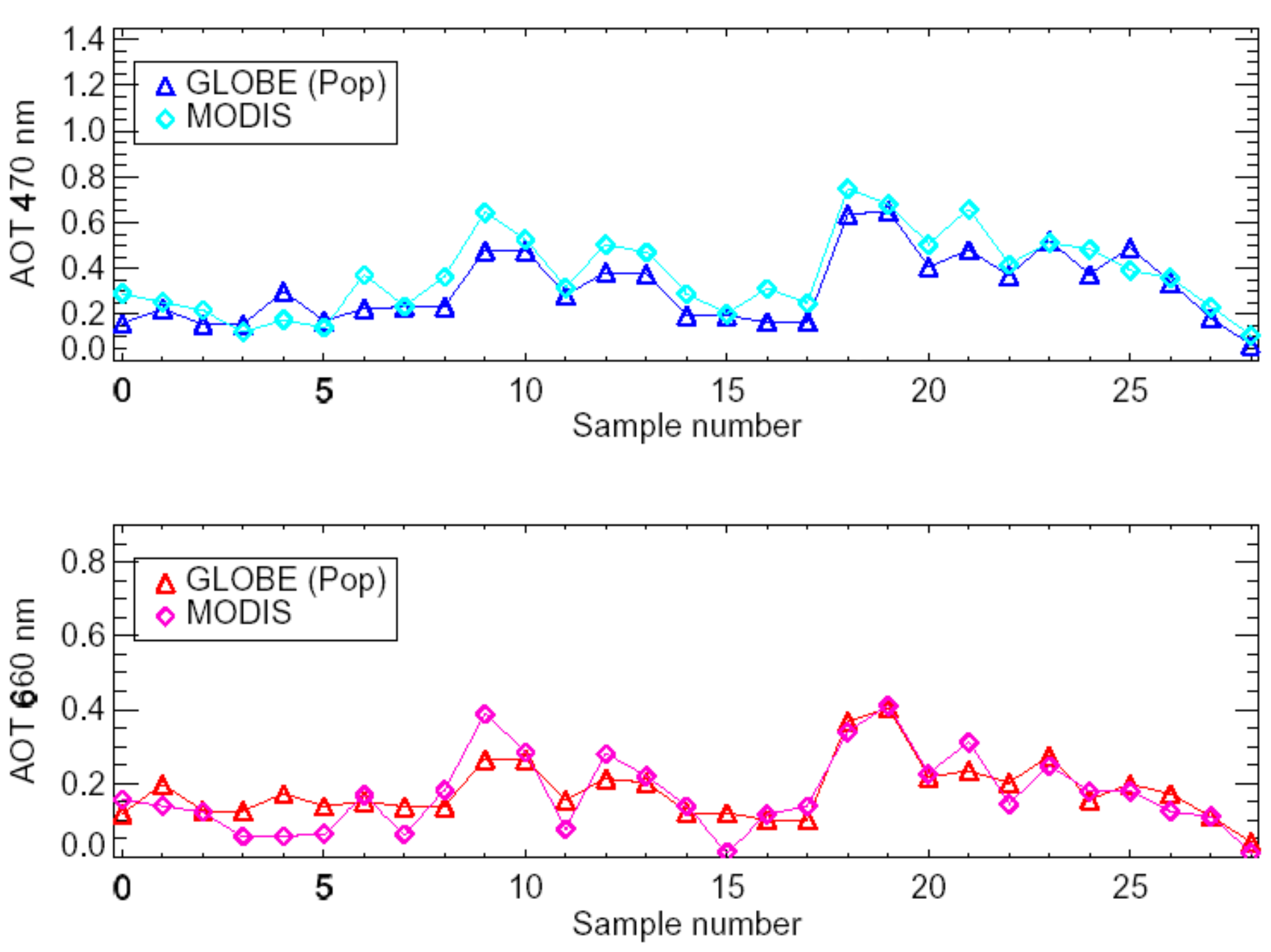
How good is AOT measured by students with a Sun photometer?

- Theoretical error analysis: precision better than 0.02 AOT
- KNMI testcase: bias <0.005, precision ~0.01 AOT
- De Populier testcase: bias < 0.04, precision ~0.03 AOT
  - time differences[30m]
  - larger distance [4km]
  - students vs. professionals
  - calibration issues

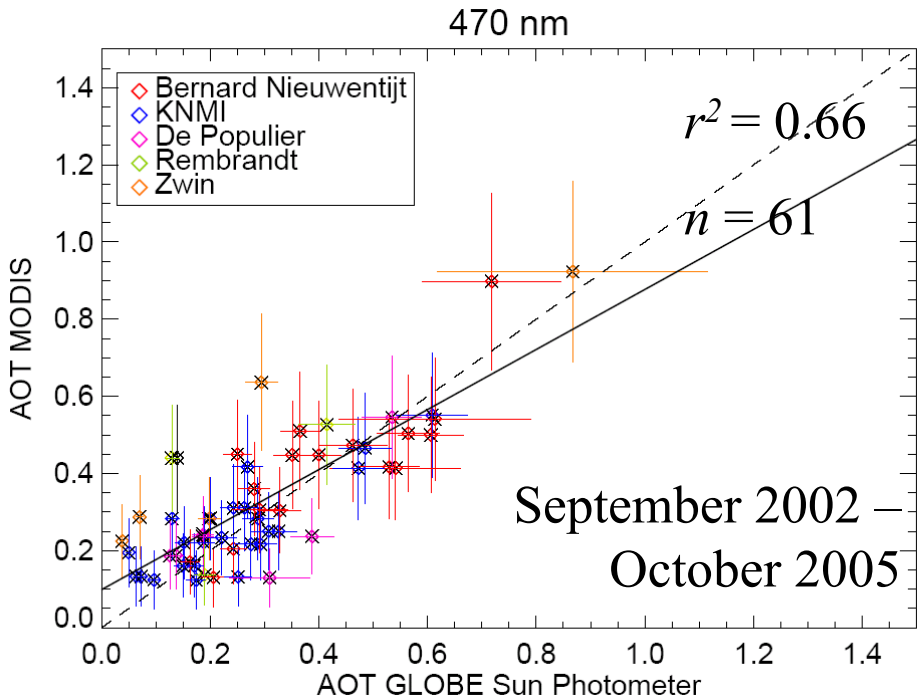
…Good enough to try and validate MODIS AOT!

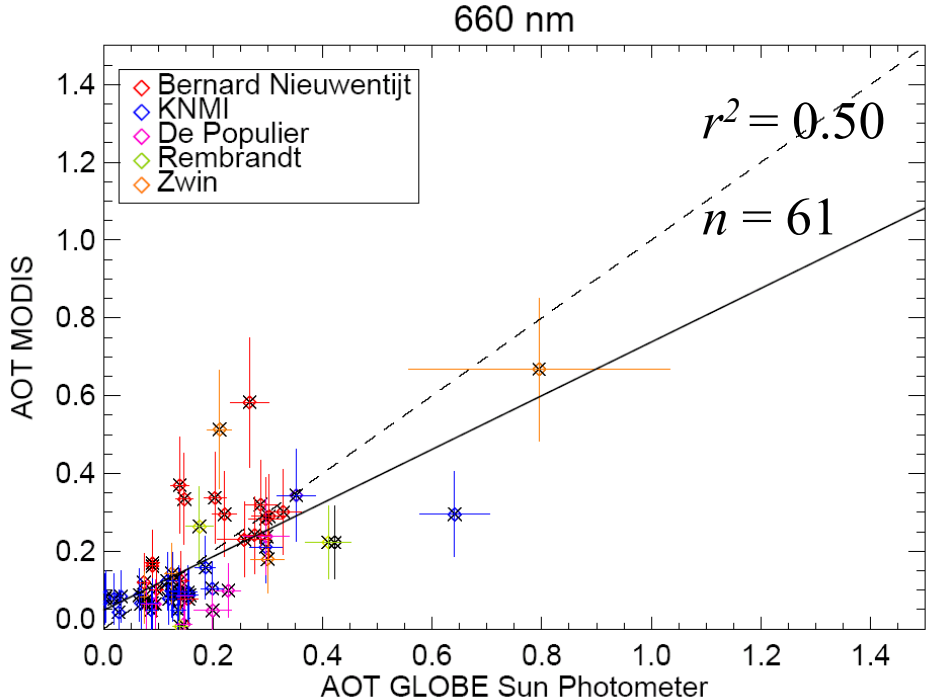
•••• The Hague school reveal land-water boundary problem with MODIS




GLOBE (Pop)
MODIS
AOT 470 nm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
Sample number
GLOBE (Pop)
MODIS
AOT 660 nm
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
Sample number

•••• MODIS vs. GLOBE AOT over the NL





bias = +0.03 AOT

RMS = 0.11 AOT

y = 0.10 + 0.78x

y = 0.09 + 0.83x

bias = -0.01 AOT

RMS = 0.11 AOT

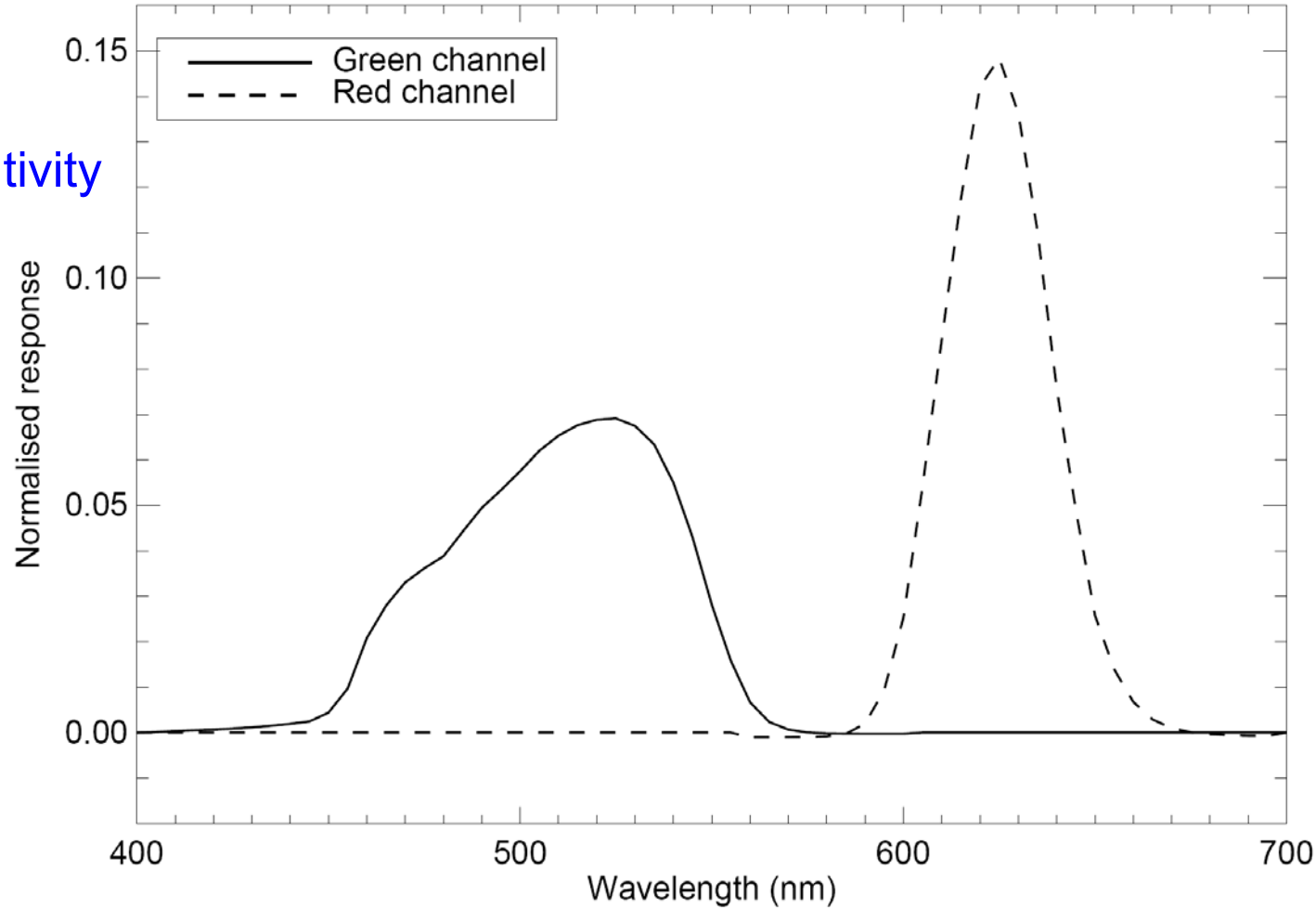
y = 0.05 + 0.69x

y = 0.06 + 0.70x

•••• Remer et al. (2005), Global validation of MODIS AOT

Instrument

Broad sensitivity



Instrument

Broad sensitivity

- Define an effective wavelength for aerosol retrieval?
- If yes, what is the stability (error) associated?

Effective wavelength

Instrument measures atmospheric transmission:

$$T = \frac{\int R(\lambda) I_0(\lambda) T(\lambda) d\lambda}{\int R(\lambda) I_0(\lambda) d\lambda}$$

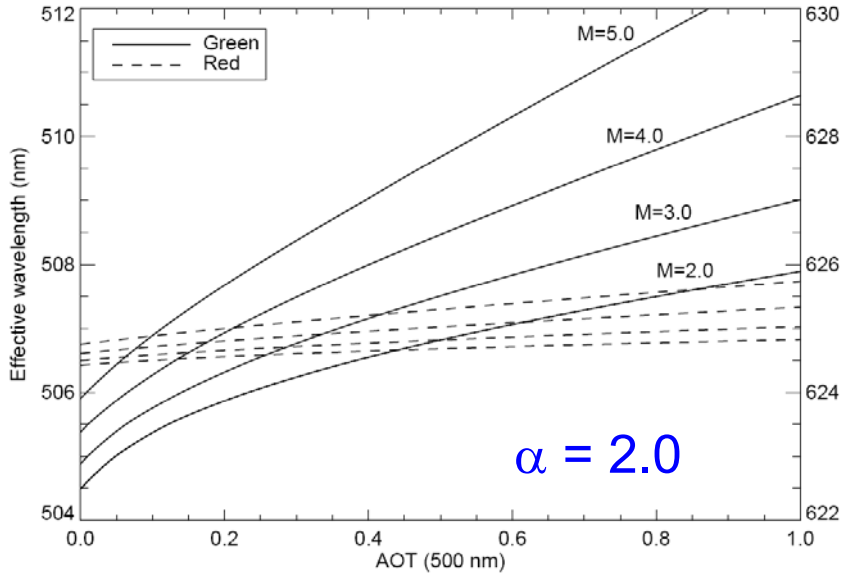
λ_{eff} is the wavelength for which it holds that:

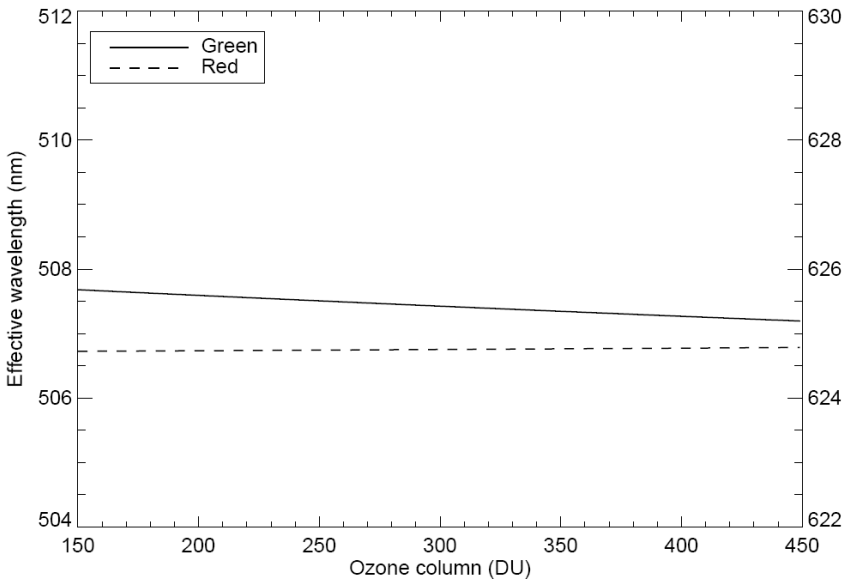
$$T = e^{-M\left(\tau_R(\lambda_{eff}) + \tau_O(\lambda_{eff}) + \tau_a(\lambda_{eff})\right)}$$

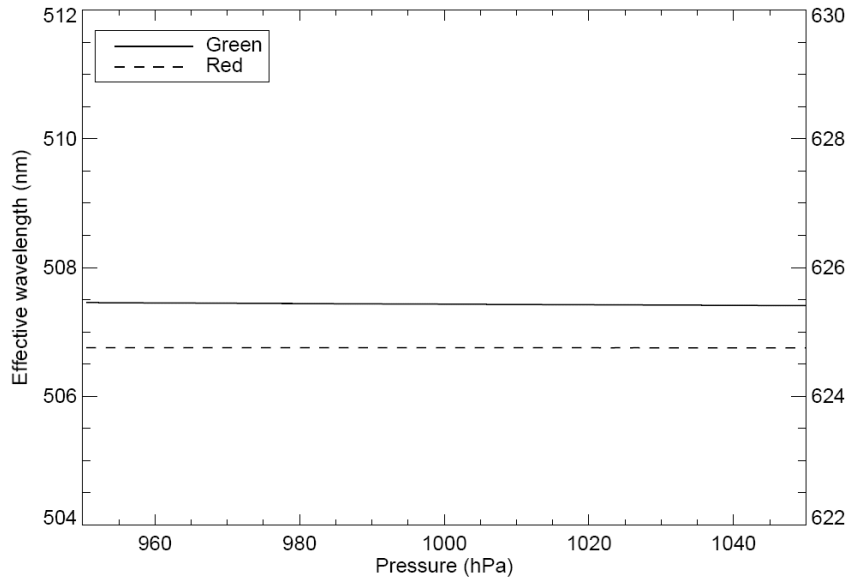
Effective wavelength

Effective wavelength thus depends on:

- $I_0(\lambda)$
- $R(\lambda)$
- $T(\lambda)$ and thus on M, τ_R, τ_O , τ_a

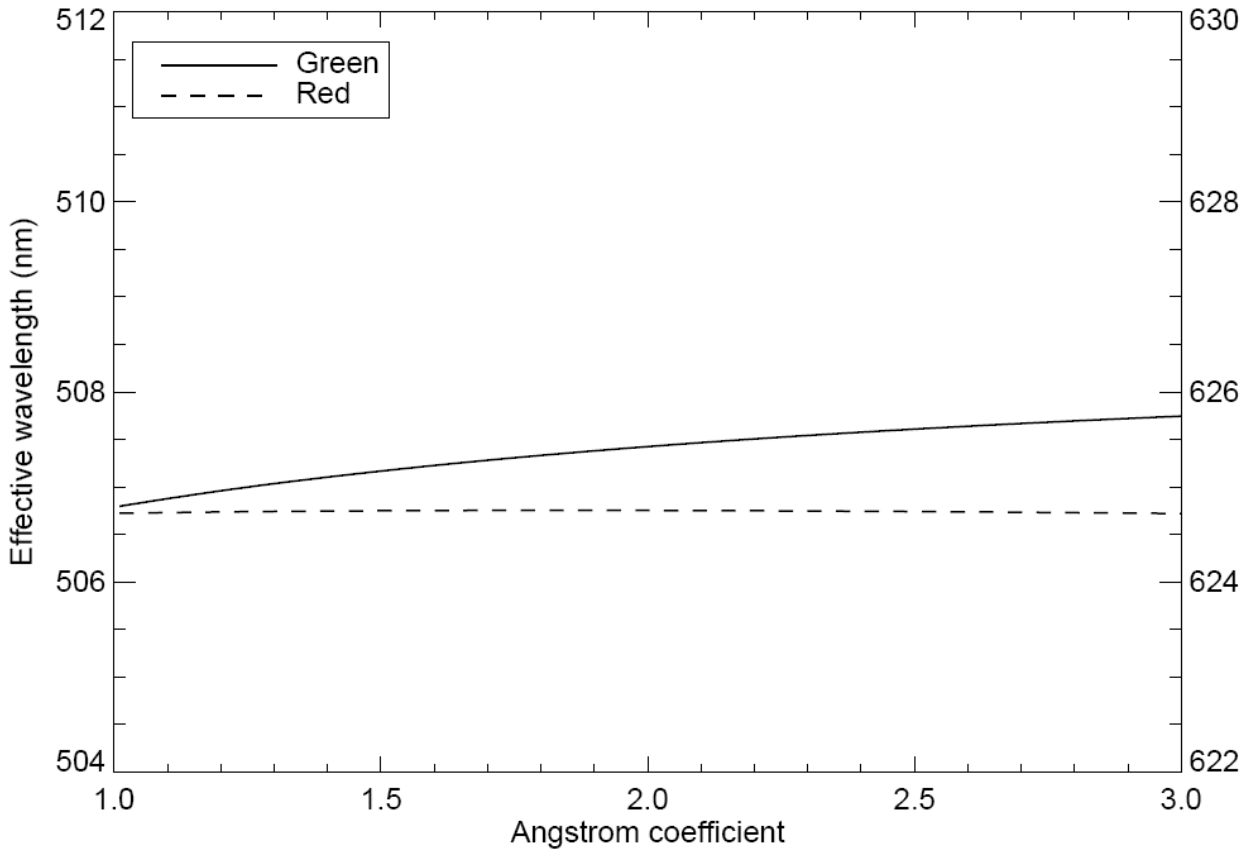






Effective wavelength

Aerosol type:



M = 2.0

AOT = 0.5

O_3 = 300 DU

p = 1013 hPa

Effective wavelength

- Neglect sensitivity to O_3, pressure, and Angstrom coefficient
- In the GLOBE project, AOT reported at fixed wavelengths:

$$\lambda_{GLOBE} = \frac{\int R(\lambda) I_0(\lambda) \lambda d\lambda}{\int R(\lambda) I_0(\lambda) d\lambda}$$

Green: 508 nm

Red: 625 nm

- Use Lookup Table to find $\lambda_{eff}(M, AOT)$ to correct for wavelength errors

$$\Delta = AOT_{508} \cdot \left(\left(\frac{\lambda_{eff}}{508.0} \right)^{\frac{-1}{\alpha}} - 1.0 \right)$$

Effective wavelength

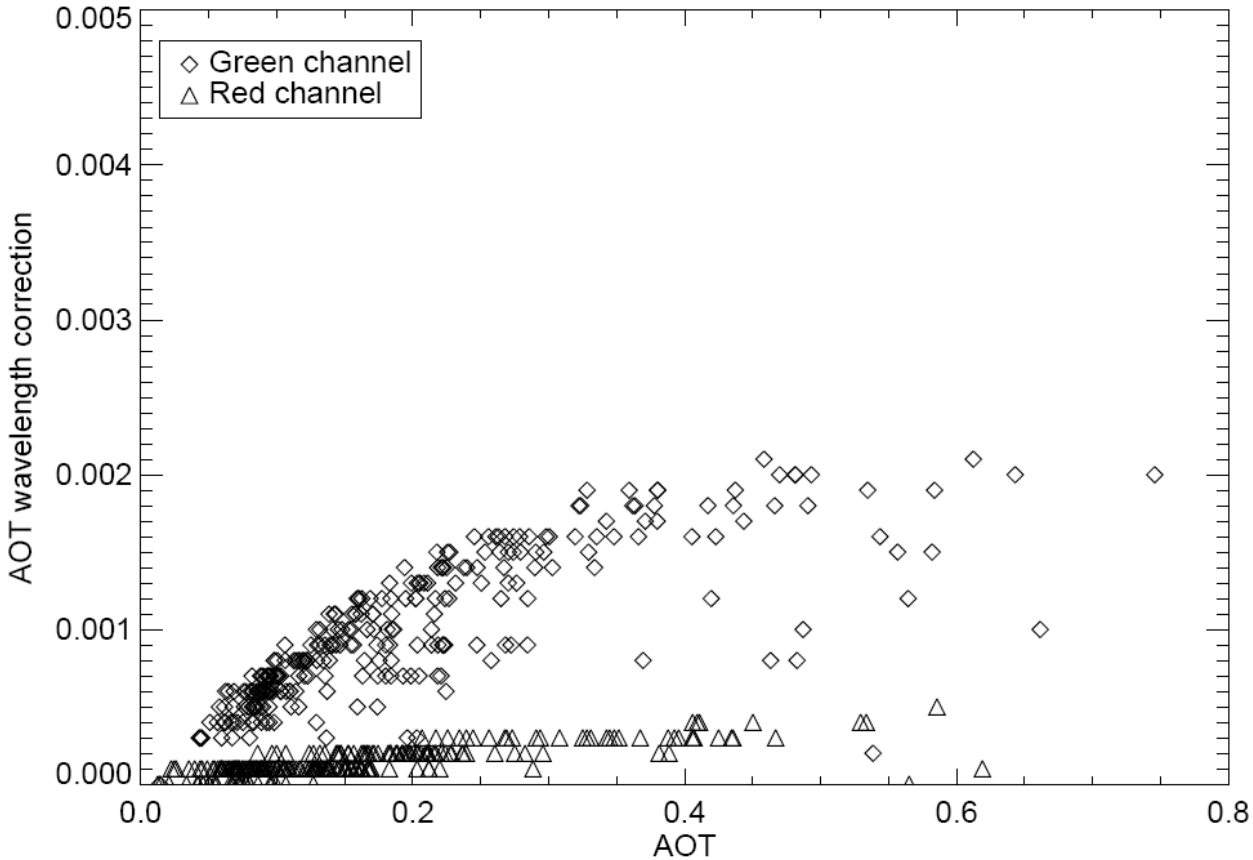
- Use Lookup Table to find $\lambda_{eff}(M, AOT)$ to correct for wavelength errors

$$\Delta = AOT_{508} \cdot \left(\left(\frac{\lambda_{eff}}{\lambda_{GLOBE}} \right)^{\frac{-1}{\alpha}} - 1.0 \right)$$

Typical corrections over the Netherlands

Range AOT 508 nm: 0.0 - 0.8

Range AOT 625 nm: 0.0 – 0.6



ΔAOT 508 < 0.002

ΔAOT 625 < 0.001

Calibration: Langley method

Conditions

- Observations of irradiance for several zenith angles

$$T = e^{-\tau} \qquad (1)$$

$$I = I_0 \cdot e^{-m\tau} \qquad (2)$$

$$\ln I = \ln I_0 + m \ln T \qquad (3)$$

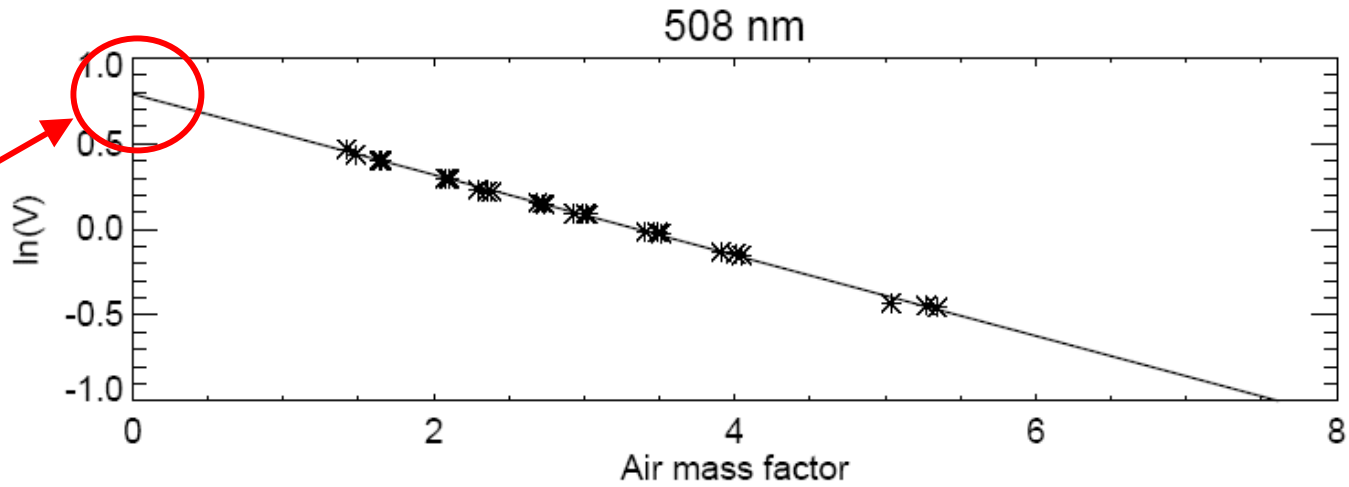
- Clear day
- Atmospheric properties (T) constant
- Correction for Earth-Sun distance
- Extrapolate to m=0: I=I_0

Langley method

7 april 2003

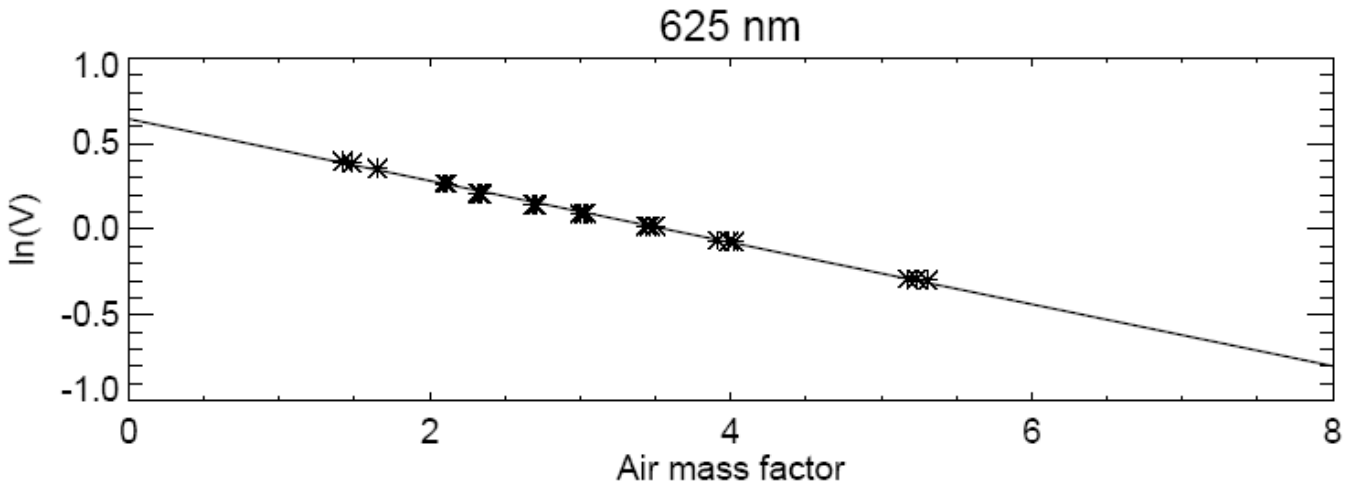
V_0 = 2.209 (±0.011)

r^2 = 0.999



V_0 = 1.907 (±0.009)

r^2 = 0.998

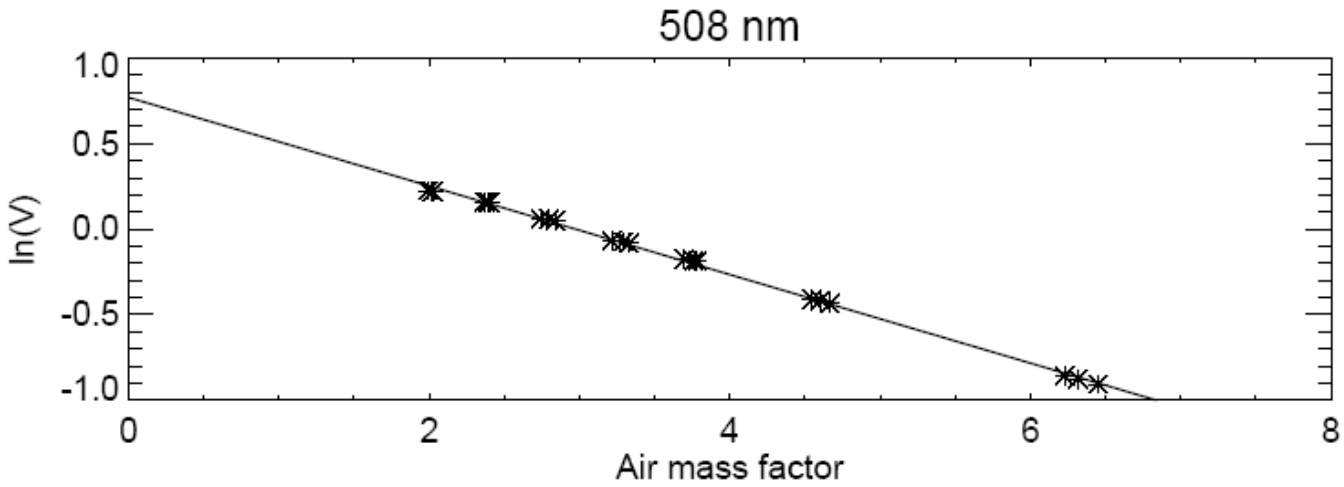


Langley method

8 april 2003

V_0 = 2.167
(±0.019)

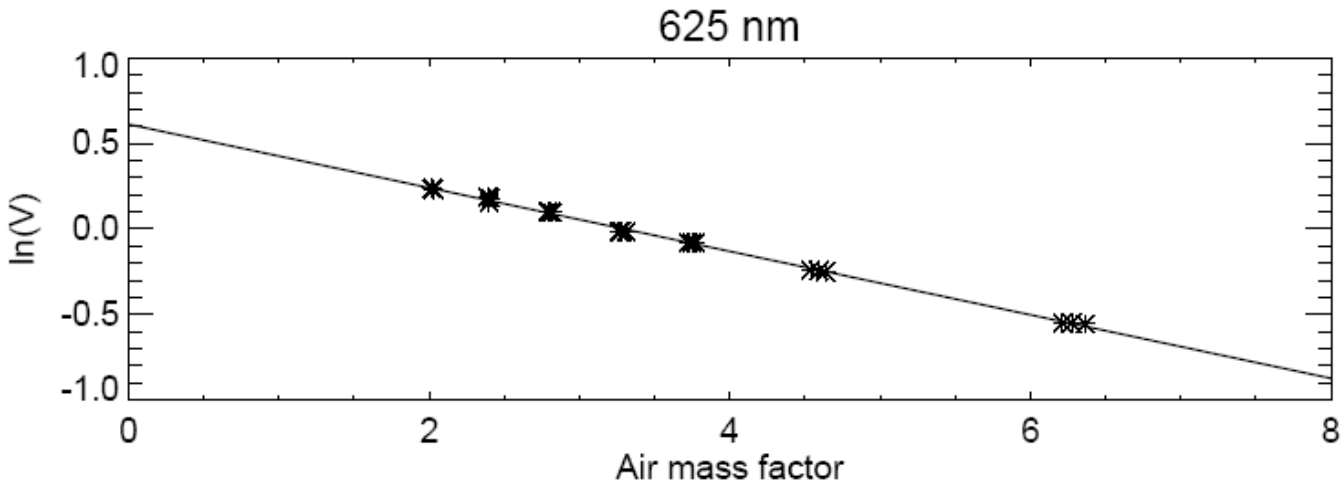
r^2 = 0.998



V_0 = 1.849

(±0.011)

r^2 = 0.999

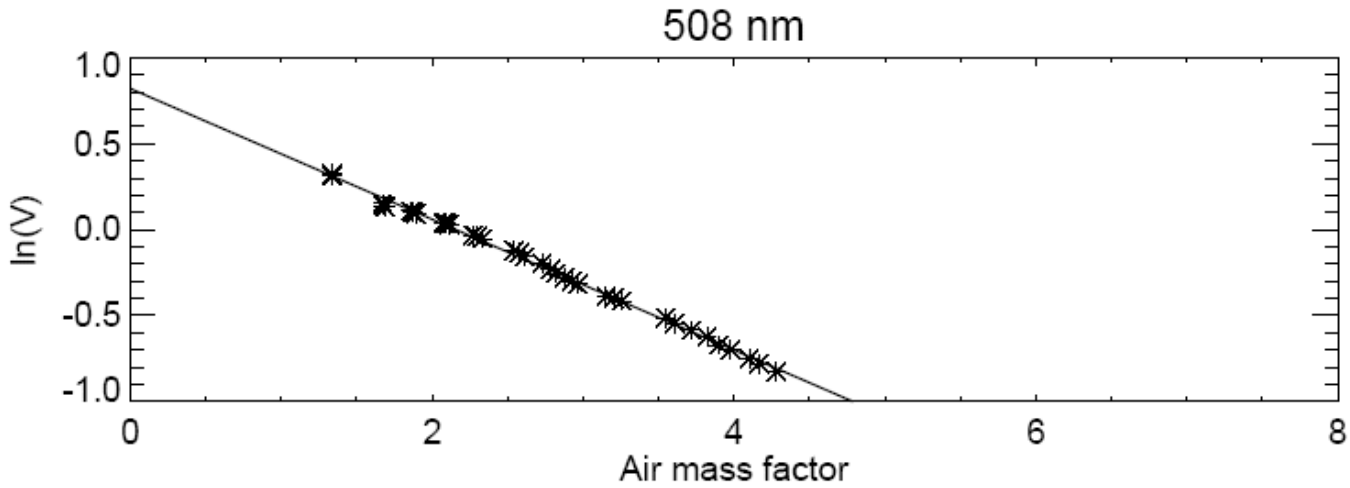


Langley method

17 april 2003

V_0 = 2.292
(±0.021)

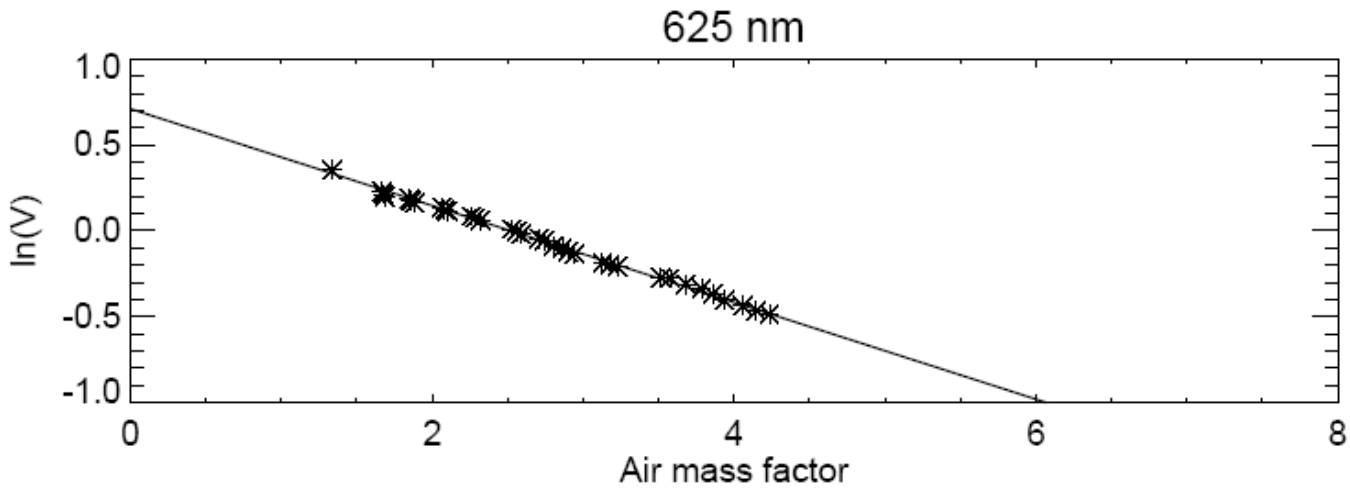
r^2 = 0.997



V_0 = 2.051

(±0.016)

r^2 = 0.997

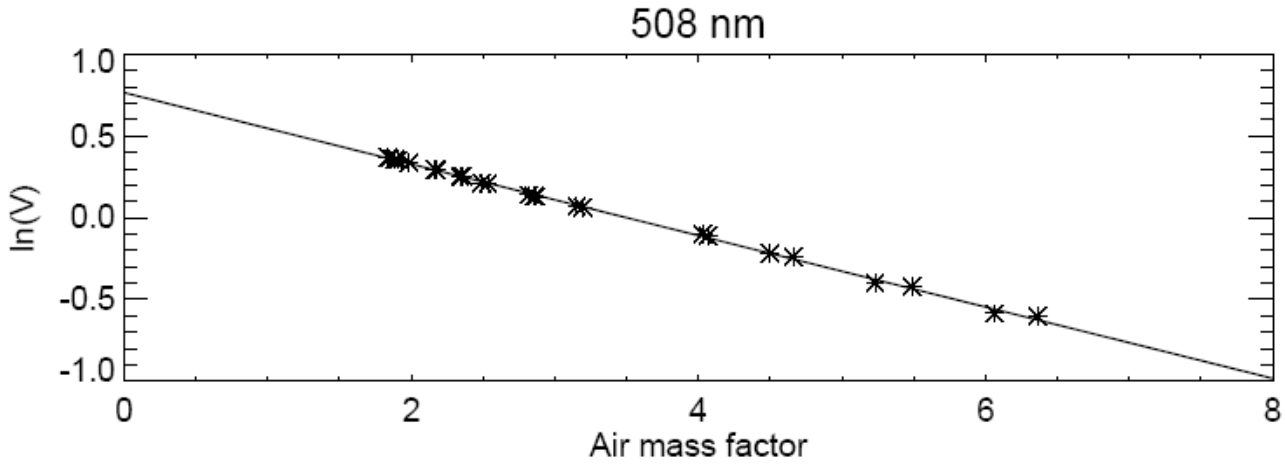


Langley method

9 september 2004

V_0 = 2.181
(±0.013)

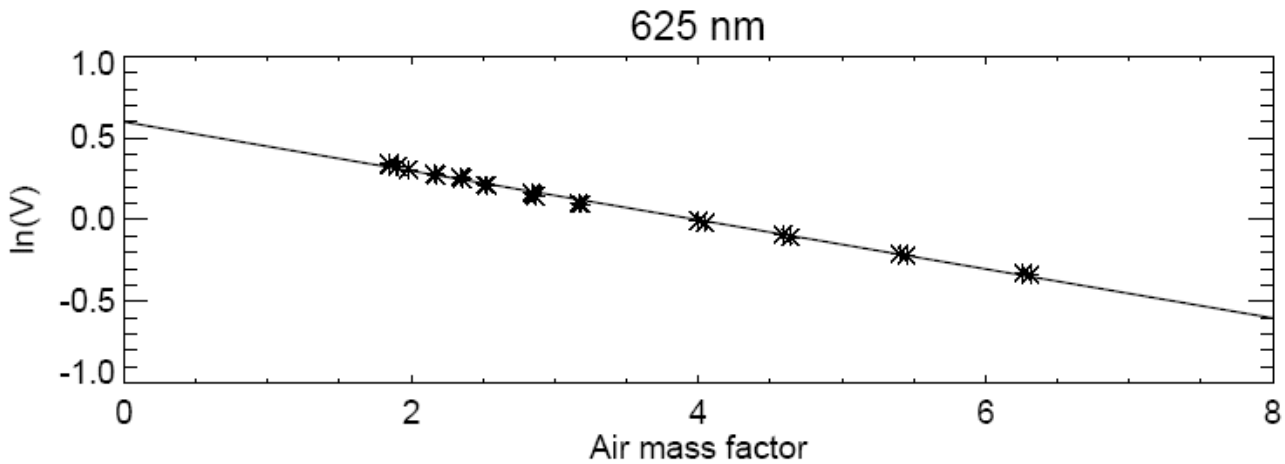
r^2 = 0.999



V_0 = 1.845

(±0.014)

r^2 = 0.996



Langley method

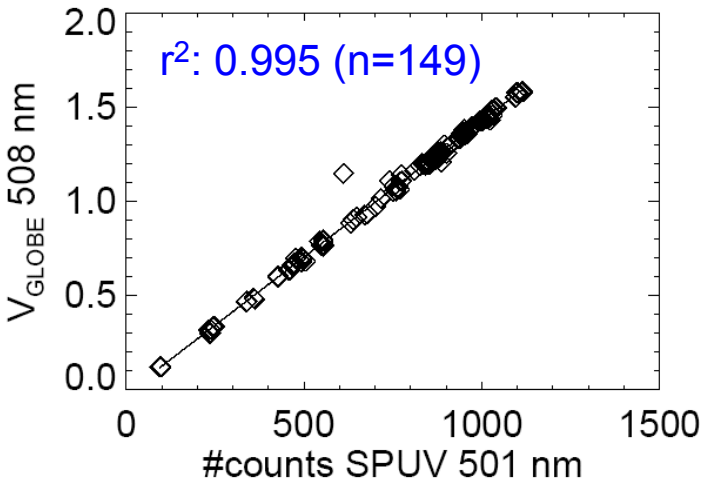
Four Langley analyses RG2-047:

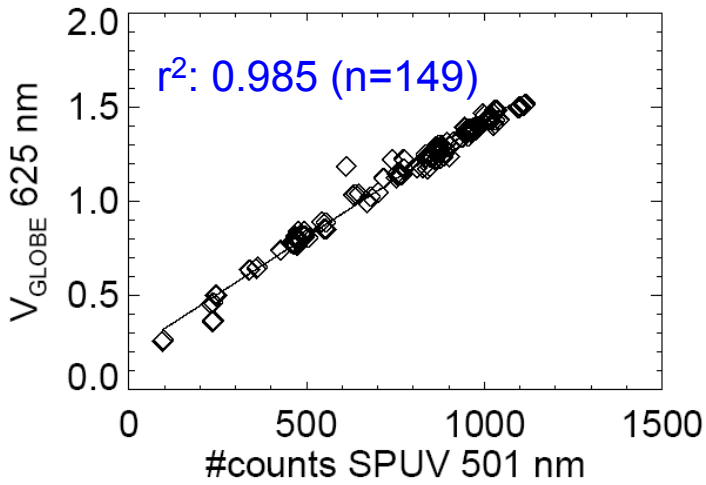
Date	V_0 Green	V_0 Red	Visibility
07-04-2003	2.209 (0.011)	1.907 (0.009)	40 km
08-04-2003	2.167 (0.019)	1.849 (0.011)	30 km
~~17-04-2003~~	~~2.292 (0.021)~~	~~2.051 (0.016)~~	~~15 km~~
09-09-2004	2.181 (0.013)	1.845 (0.014)	25 km
Average	2.186 (0.021)	1.867 (0.035)	

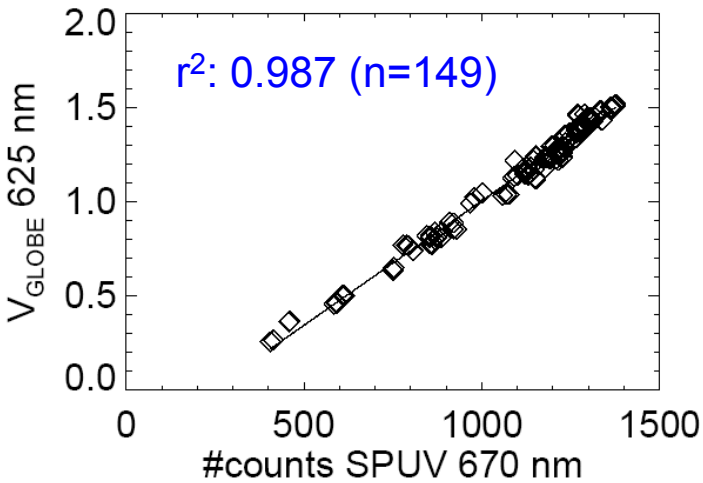
GLOBE calibration concept

- No calibration relative to SPUV
- Demonstration project
- Comparison with SPUV gives impression of quality of retrieval
- Differences due to
  - calibration differences
  - algorithm differences

Comparing GLOBE and SPUV voltages







Simultaneous collocated observations

September 2002 - April 2003

Comparing GLOBE and SPUV AOTs

Use Angstrom's relationship:

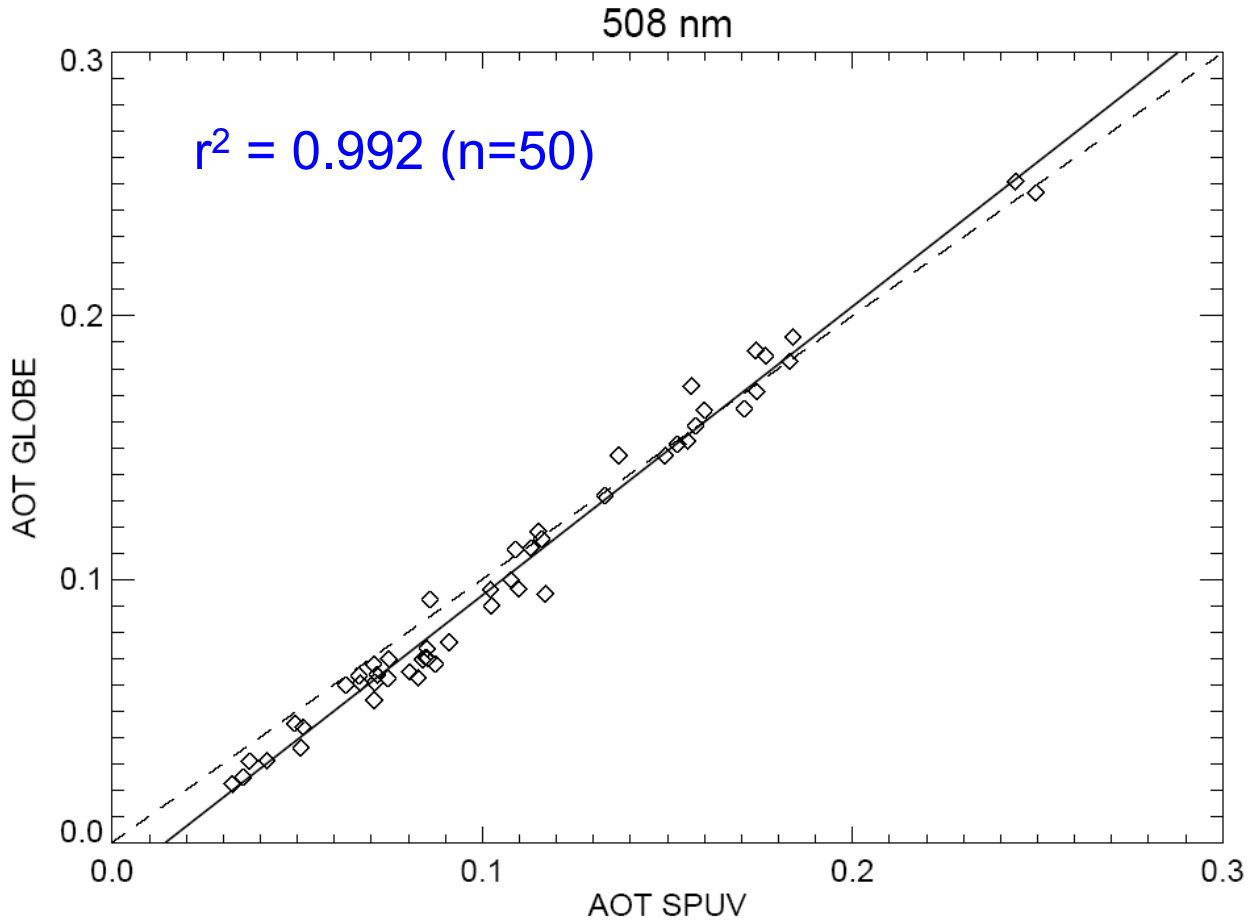
$$\tau_{SPUV,\lambda_1} = \tau_{SPUV,\lambda_2} \cdot \left(\frac{\lambda_1}{\lambda_2} \right)^{-\alpha}$$

λ_1: GLOBE wavelength

λ_2: SPUV wavelength

α: Angstrom coefficient (from SPUV 501 nm and 670 nm)

Comparing GLOBE and SPUV AOTs

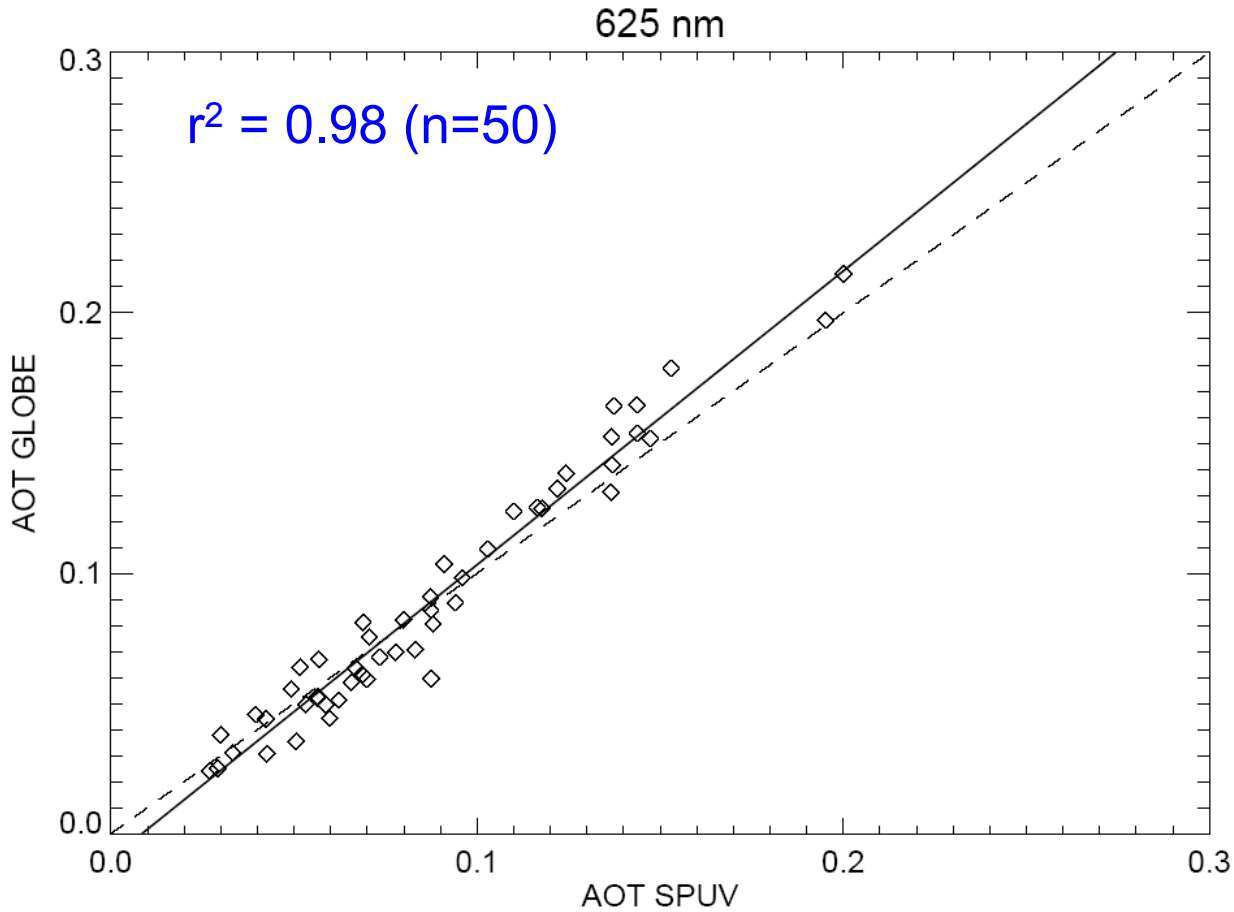


y = -0.02+1.10x ($\pm$0.06)

Av. bias: -0.005

RMS: 0.009

Comparing GLOBE and SPUV AOTs



y = -0.01+1.13x (±0.08)

Av. bias: +0.002

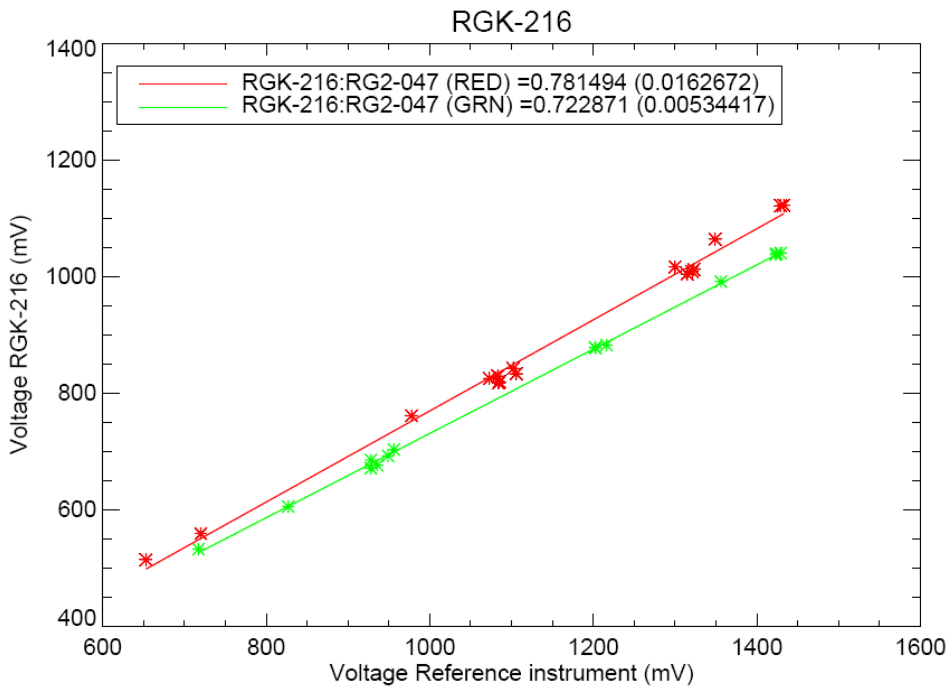
RMS: 0.011

GLOBE calibration concept

- Calibration constants for all schools relative to RG2-047:

$$V_{0,school} = V_{0,RG2-047} \cdot R$$

- R: instrument ratios from simultaneous measurements



- Advantage:
  - Independent retrievals
  - Demonstrate attainable accuracy with independent approach

Comparing GLOBE and AERONET AOTs in The Hague

Use Angstrom's relationship:

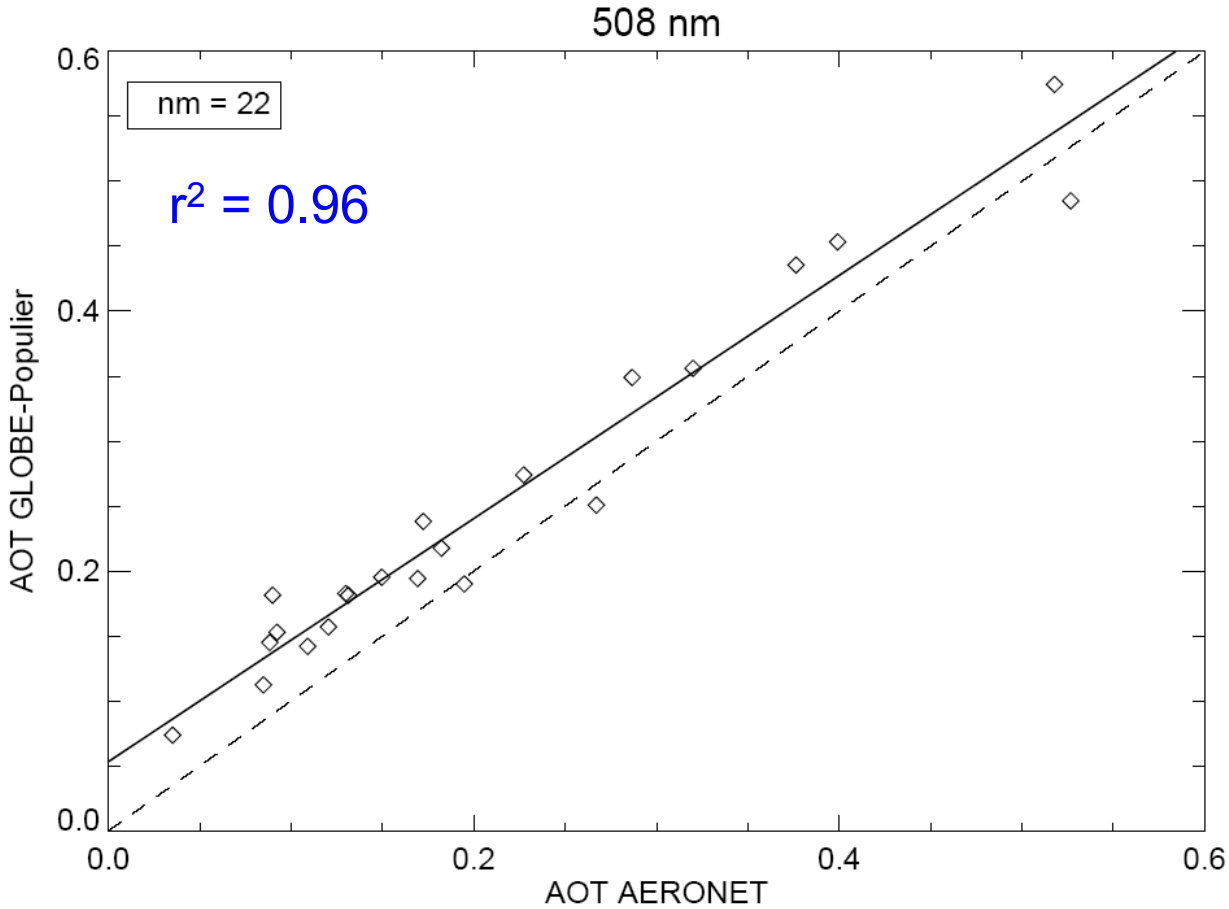
$$\tau_{AERONET,\lambda_1} = \tau_{AERONET,\lambda_2} \cdot \left(\frac{\lambda_1}{\lambda_2} \right)^{-\alpha}$$

λ_1: GLOBE wavelength

λ_2: AERONET wavelength

α: Angstrom coefficient (from AERONET 440 nm and 670 nm)

Comparing GLOBE and AERONET AOTs in The Hague

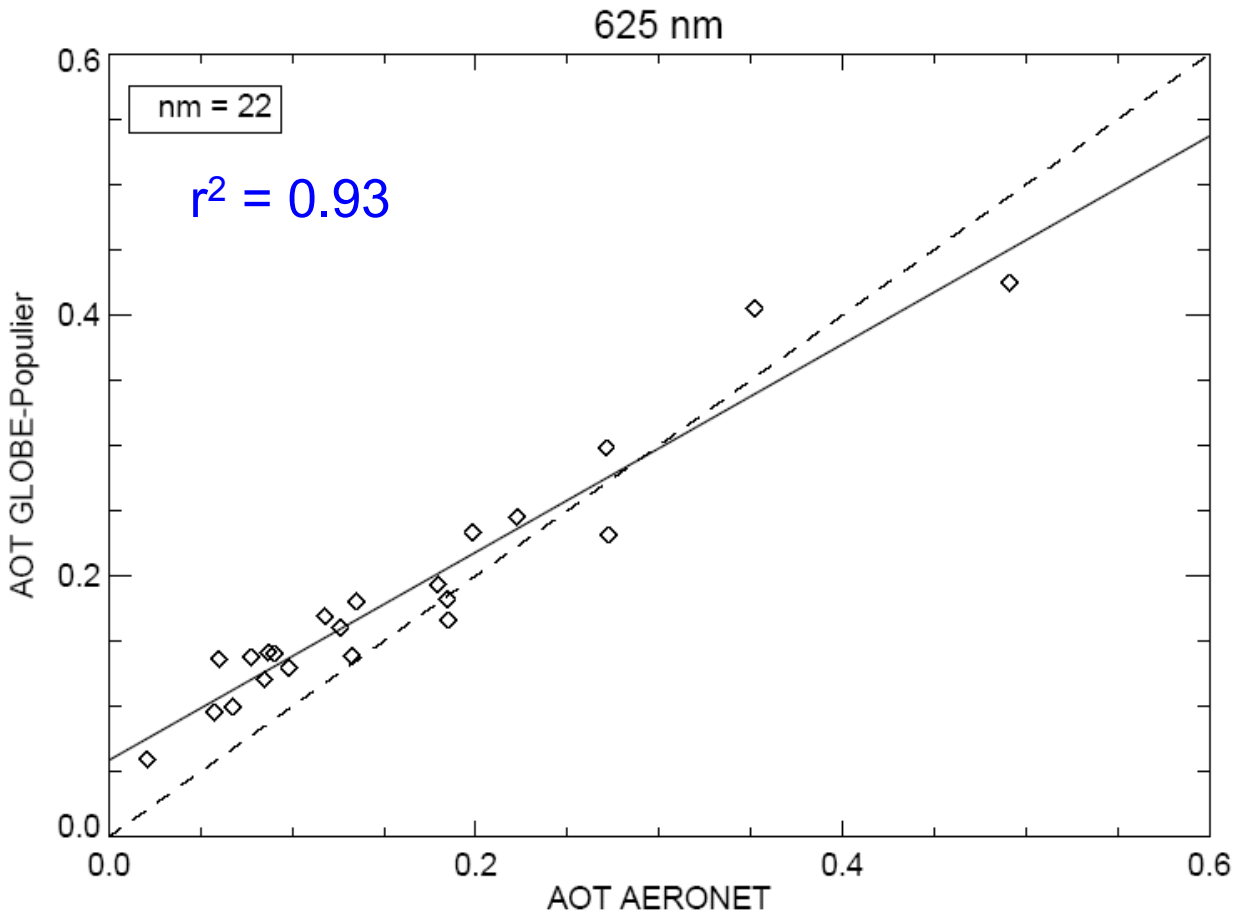


$y = 0.05+0.94x$ (± 0.05)

Av. bias: +0.04

RMS: 0.03

Comparing GLOBE and AERONET AOTs in The Hague



$y = 0.06+0.80x$ (± 0.05)

Av. bias: +0.03

RMS: 0.03

Comparing GLOBE and AERONET AOTs in The Hague

- Calibration constants derived from RG2-047
- Demonstration project
- Small bias, excellent correlations: students can do it!
- Differences due to (note: n = 22)
  - calibration differences
  - algorithm differences

Validation of MODIS AOT with GLOBE schools in the NL

How?

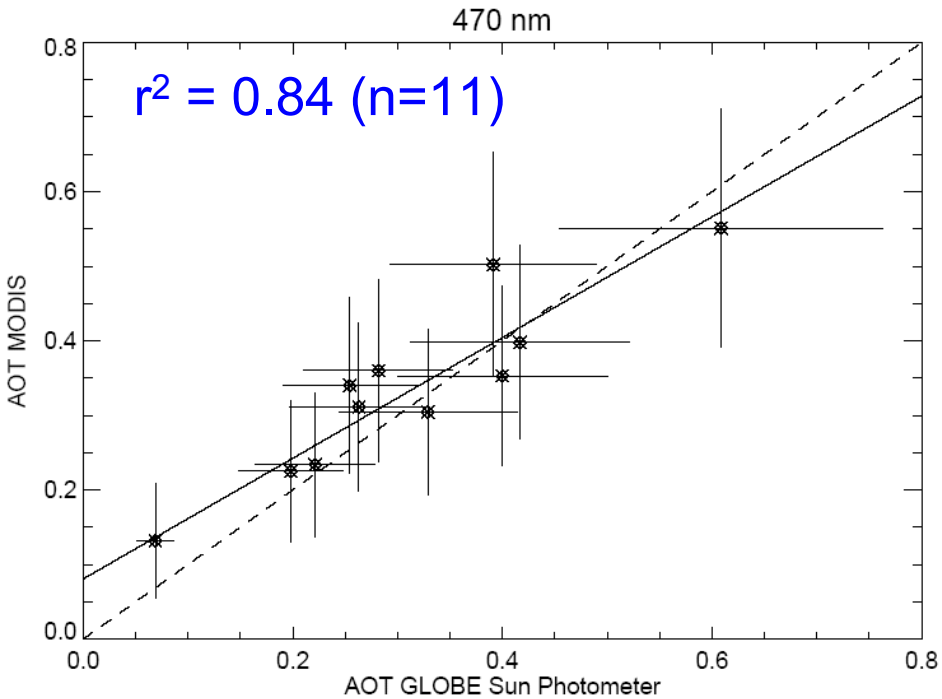
- MODIS AOT at 470 nm and 660 nm
- Extrapolate GLOBE AOT to MODIS with GLOBE Angstrom coeff.

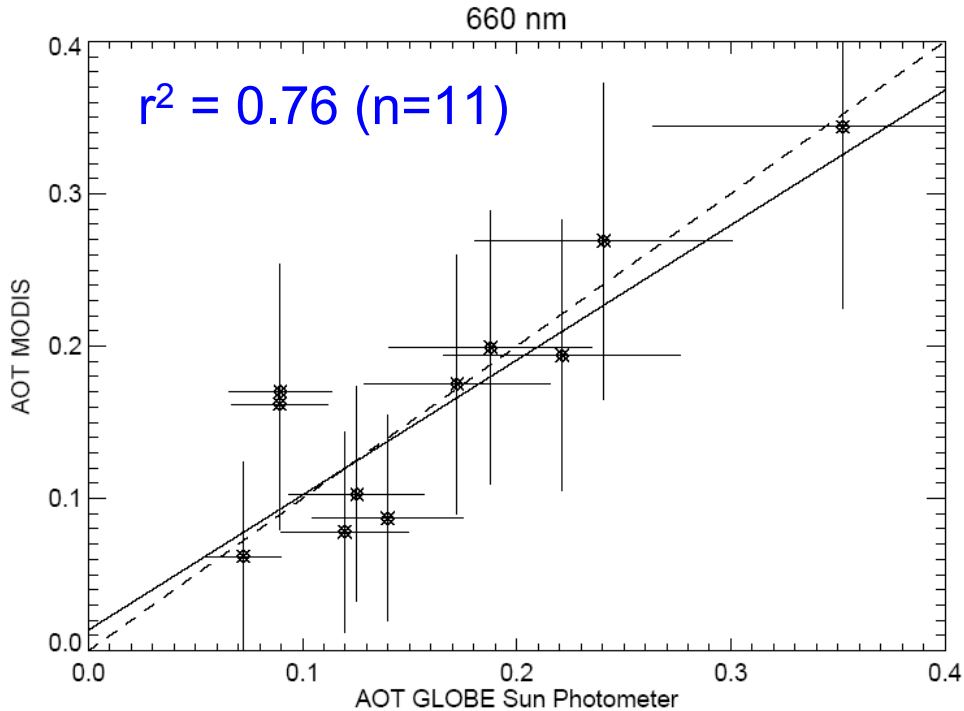
Criteria

- School location within MODIS pixel
- $|\Delta t| < 10'$
- n = 11:

Validation of MODIS AOT with GLOBE schools in the NL

All data





$y = 0.08+0.81x$ (± 0.28)

Av. bias: +0.03

RMS: 0.06

$y = 0.01+0.89x$ (± 0.41)

Av. bias: +0.003

RMS: 0.043

Validation of MODIS AOT with GLOBE schools in the NL

How?

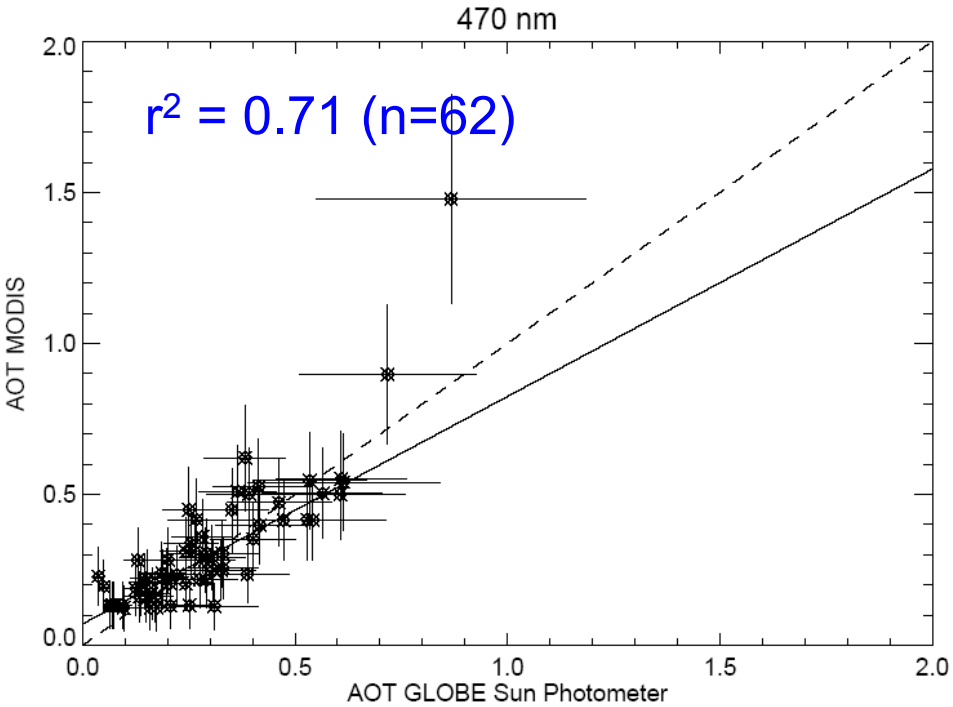
- MODIS AOT at 470 nm and 660 nm
- Extrapolate GLOBE AOT to MODIS with GLOBE Angstrom coeff.

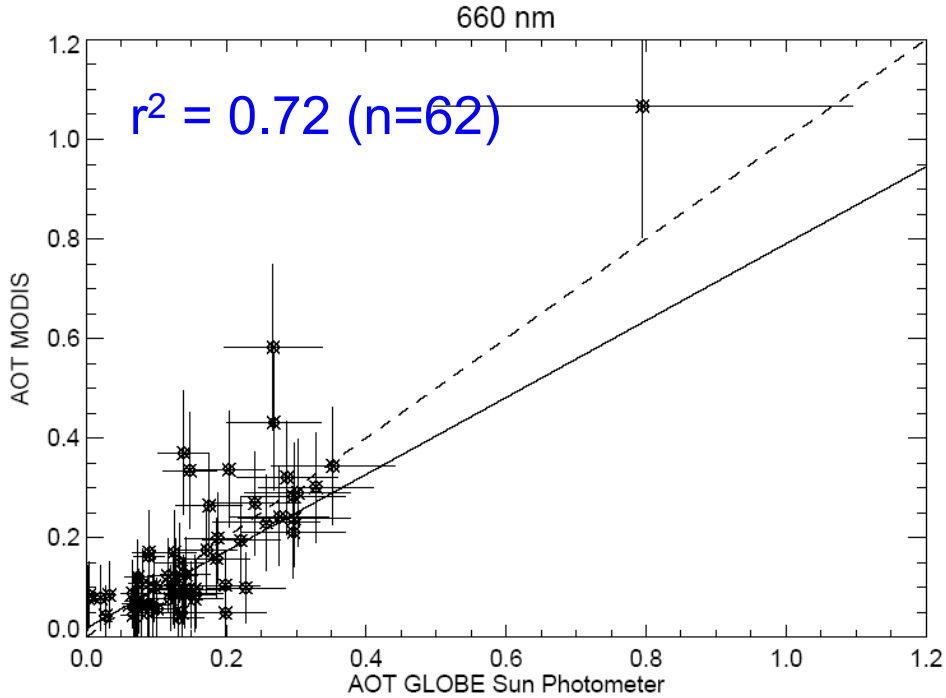
Criteria

- School location within MODIS pixel
- $|\Delta t| < 3$ hours to generate statistics

Validation of MODIS AOT with GLOBE schools in the NL

All data





$y = 0.07+0.75x$ (± 0.11)

Av. bias: +0.03

RMS: 0.12

$y = 0.02+0.77x$ (± 0.14)

Av. bias: +0.01

RMS: 0.09

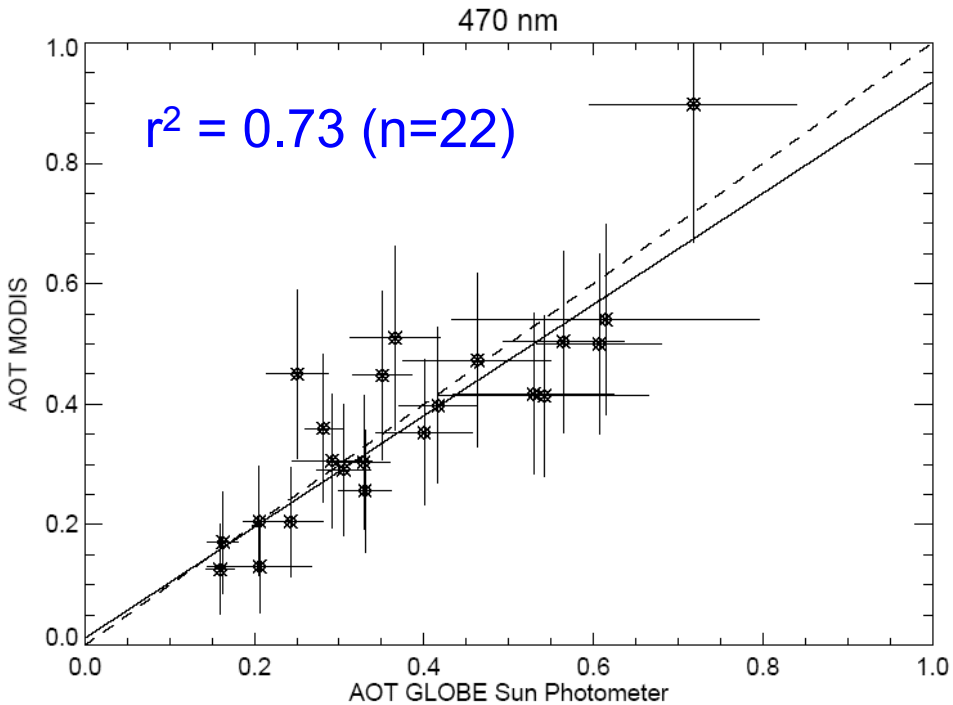
Validation of MODIS AOT with GLOBE schools in the NL

Increasing time criterion does not (significantly) affect

- Slope
- Av.bias stays the same
- RMS doubles

Validation of MODIS AOT with GLOBE schools in the NL

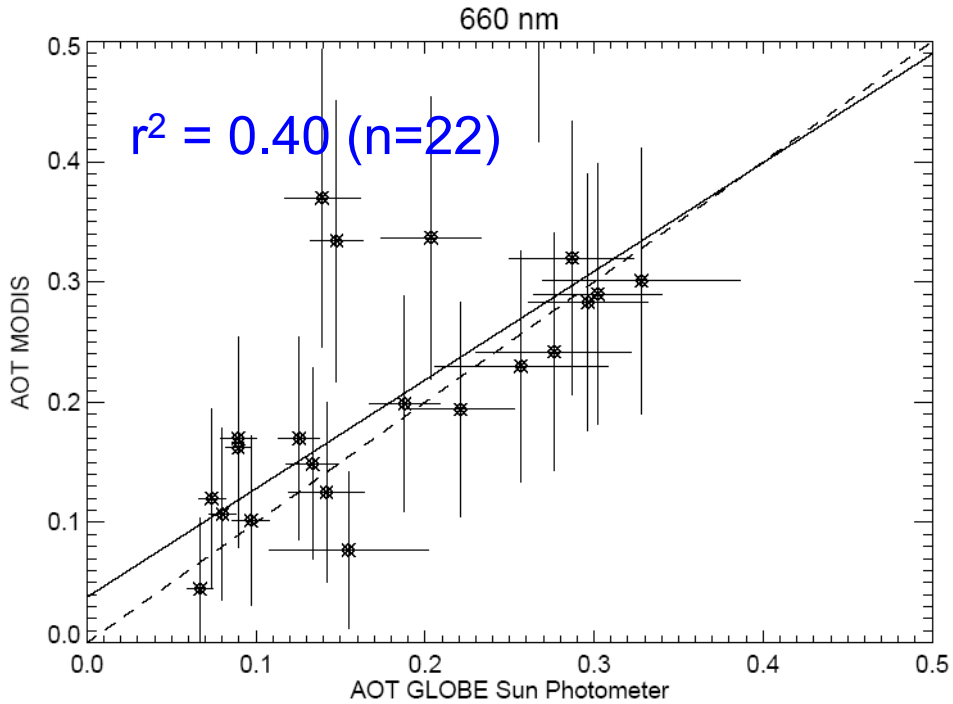
Bernard Nieuwentijt - Amsterdam



y = 0.01+0.94*x* (±0.22)

Av. bias: -0.003

RMS: 0.091



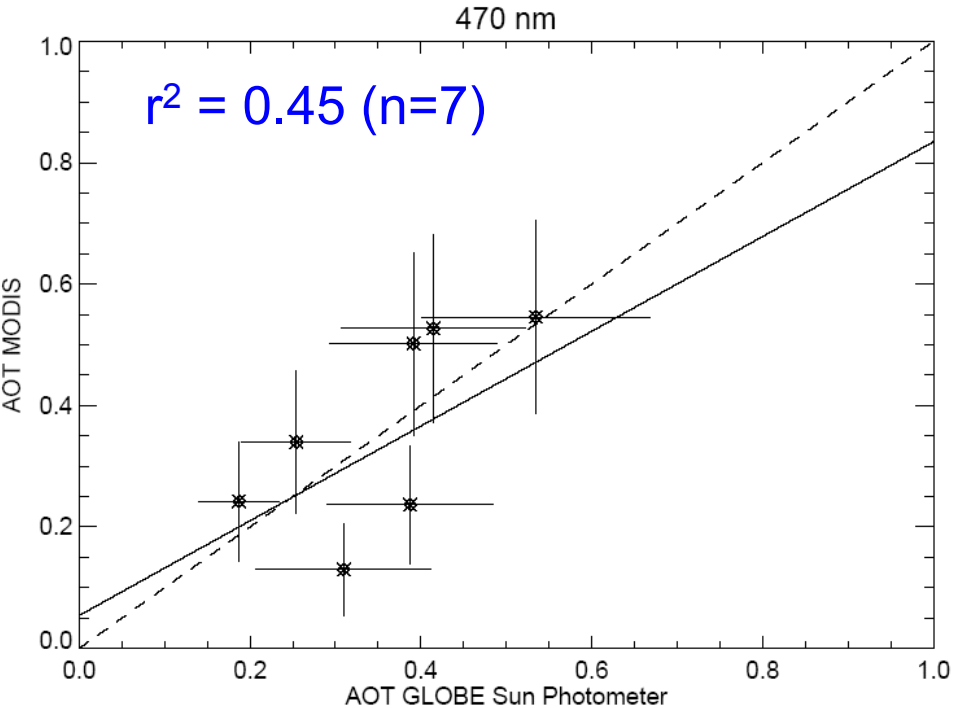
y = 0.04+0.91*x* (±0.27)

Av. bias: +0.043

RMS: 0.096

Validation of MODIS AOT with GLOBE schools in the NL

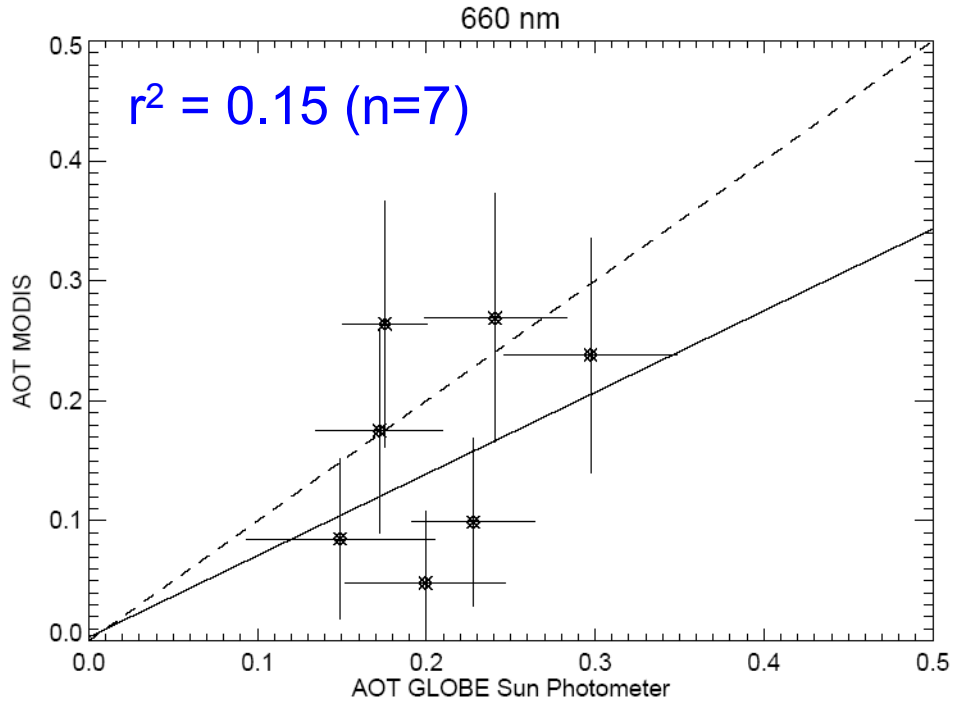
De Populier – The Hague



$y = 0.05+0.78x$ (± 0.51)

Av. bias: +0.01

RMS: 0.12



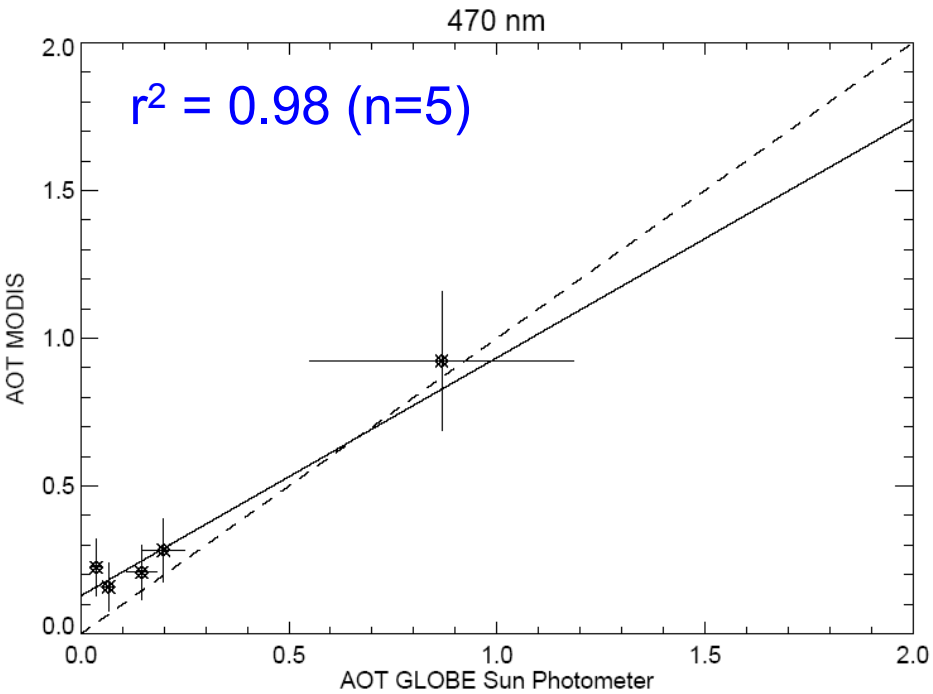
$y = -0.002+0.70x$ (± 0.80)

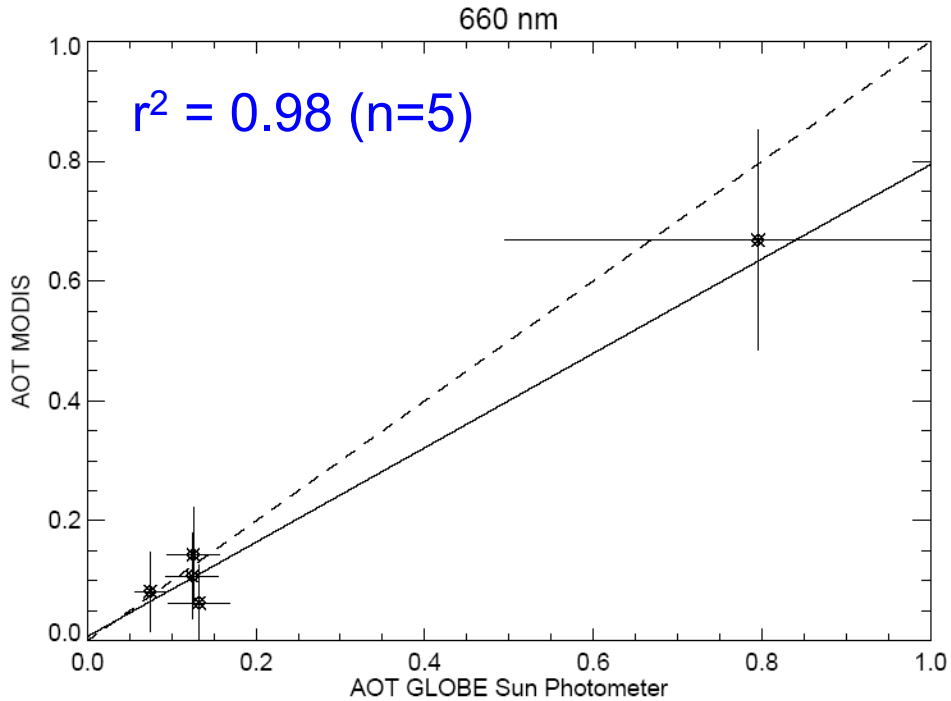
Av. bias: -0.04

RMS: 0.09

Validation of MODIS AOT with GLOBE schools in the NL

Zwin – Oostburg





$y = 0.13+0.81x$ (± 0.41)

Av. bias: +0.10

RMS: 0.05

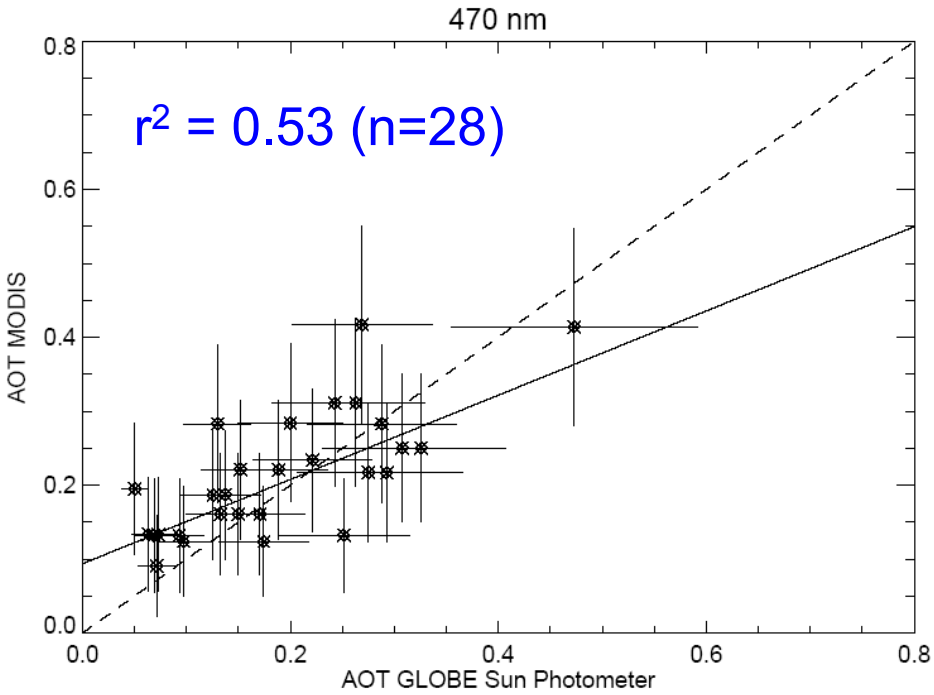
$y = 0.01+0.79x$ (± 0.43)

Av. bias: -0.04

RMS: 0.06

Validation of MODIS AOT with GLOBE schools in the NL

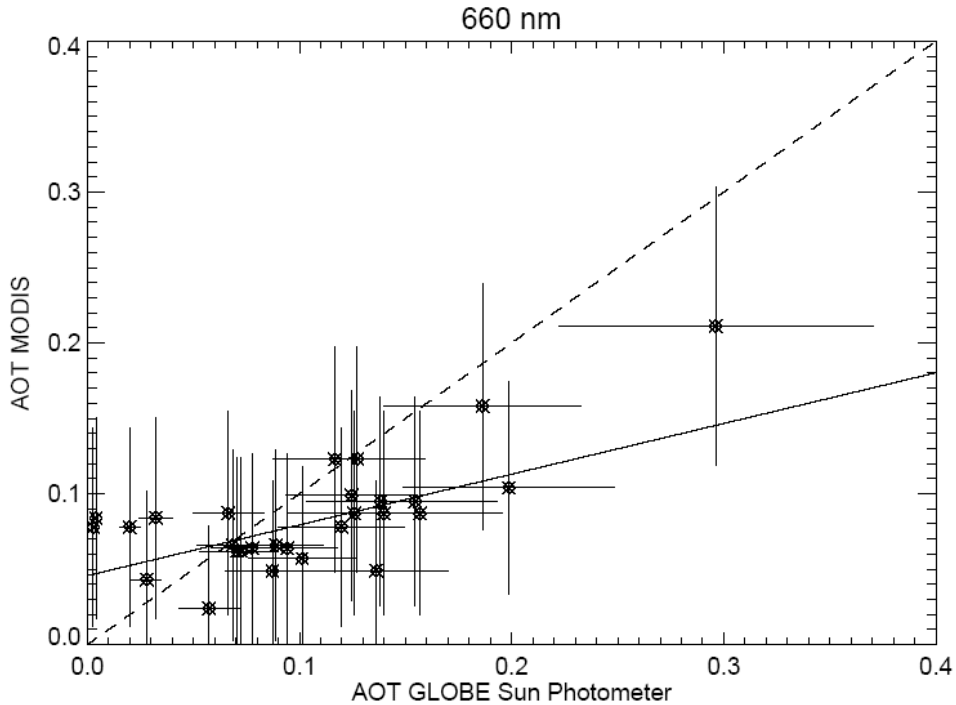
KNMI – De Bilt



$y = 0.10+0.53x$ (± 0.20)

Av. bias: +0.02

RMS: 0.07



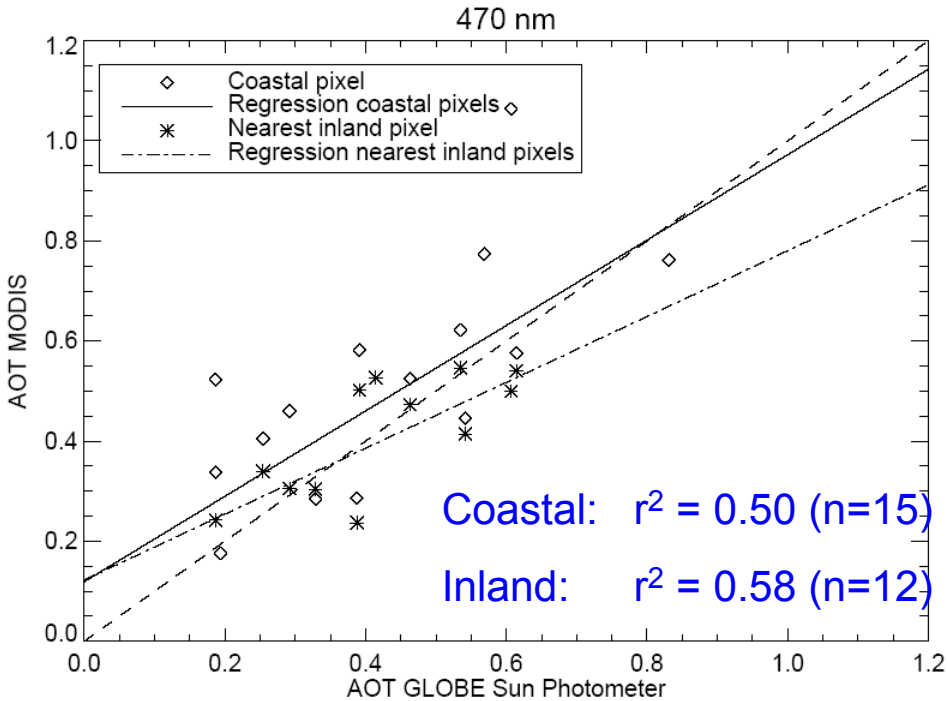
$y = 0.05+0.31x$ (± 0.23)

Av. bias: -0.02

RMS: 0.05

Validation of MODIS AOT in coastal regions

Marken and The Hague locations, 3 hour time difference

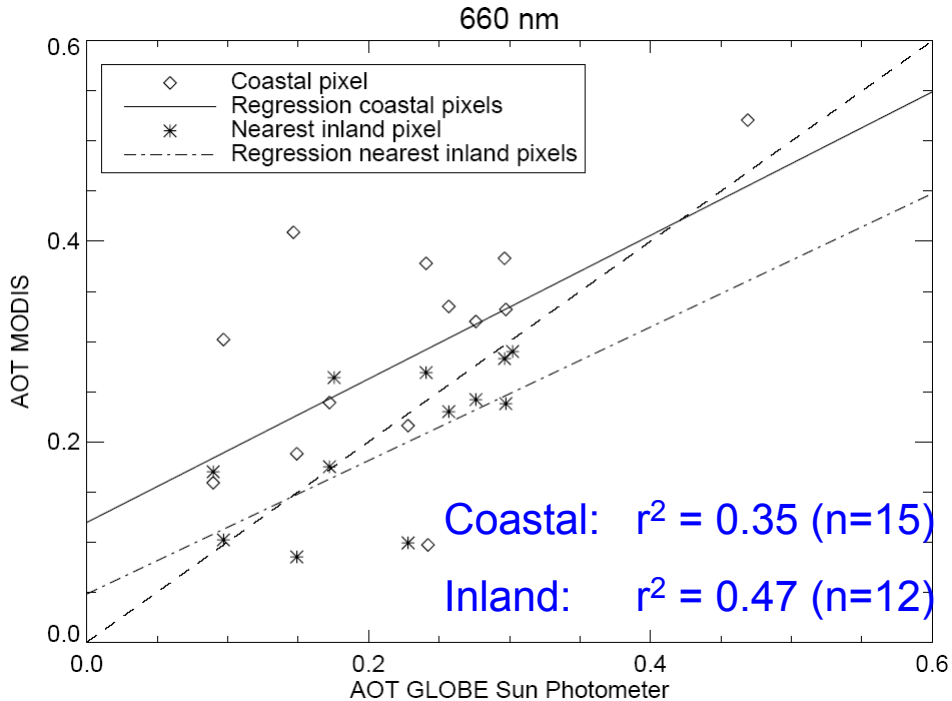


Coastal: r^2 = 0.50 (n=15)

Inland: r^2 = 0.58 (n=12)

Coastal av. bias: +0.10 (0.16)

Inland av. bias: -0.01 (0.09)



Coastal: r^2 = 0.35 (n=15)

Inland: r^2 = 0.47 (n=12)

Coastal av. bias: +0.09 (0.15)

Inland av. bias: -0.01 (0.06)

Extra slides

Comparing Angstrom coefficients in De Bilt

- SPUV 501-670 nm: 1.15 ± 0.34 (n = 50)
- GLOBE 508-625 nm: 0.66 ± 0.73

AOT 508 nm > 0.15

- SPUV 501-670 nm: 1.11 ± 0.39 (n=13)
- GLOBE 508-625 nm: 0.73 ± 0.36

Extra slides

Comparing Angstrom coefficients in The Hague

- AERONET 440-670 nm: 1.46 ± 0.62 (n = 22)
- GLOBE 508-625 nm: 1.35 ± 0.65

AOT 508 nm > 0.15

- AERONET 440-670 nm: 1.44 ± 0.58 (n=18)
- GLOBE 508-625 nm: 1.43 ± 0.66